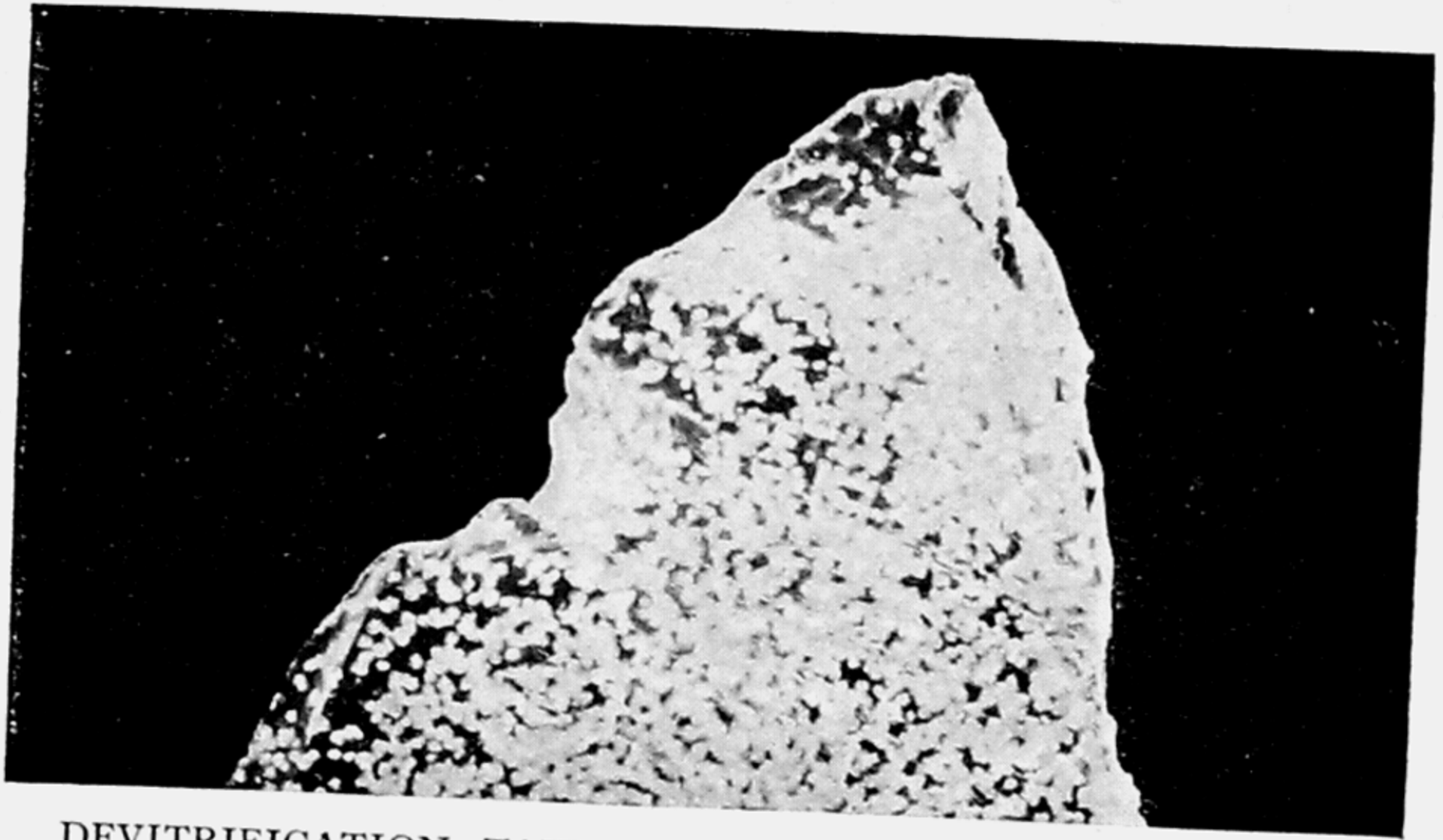


# GENERAL SCIENCE

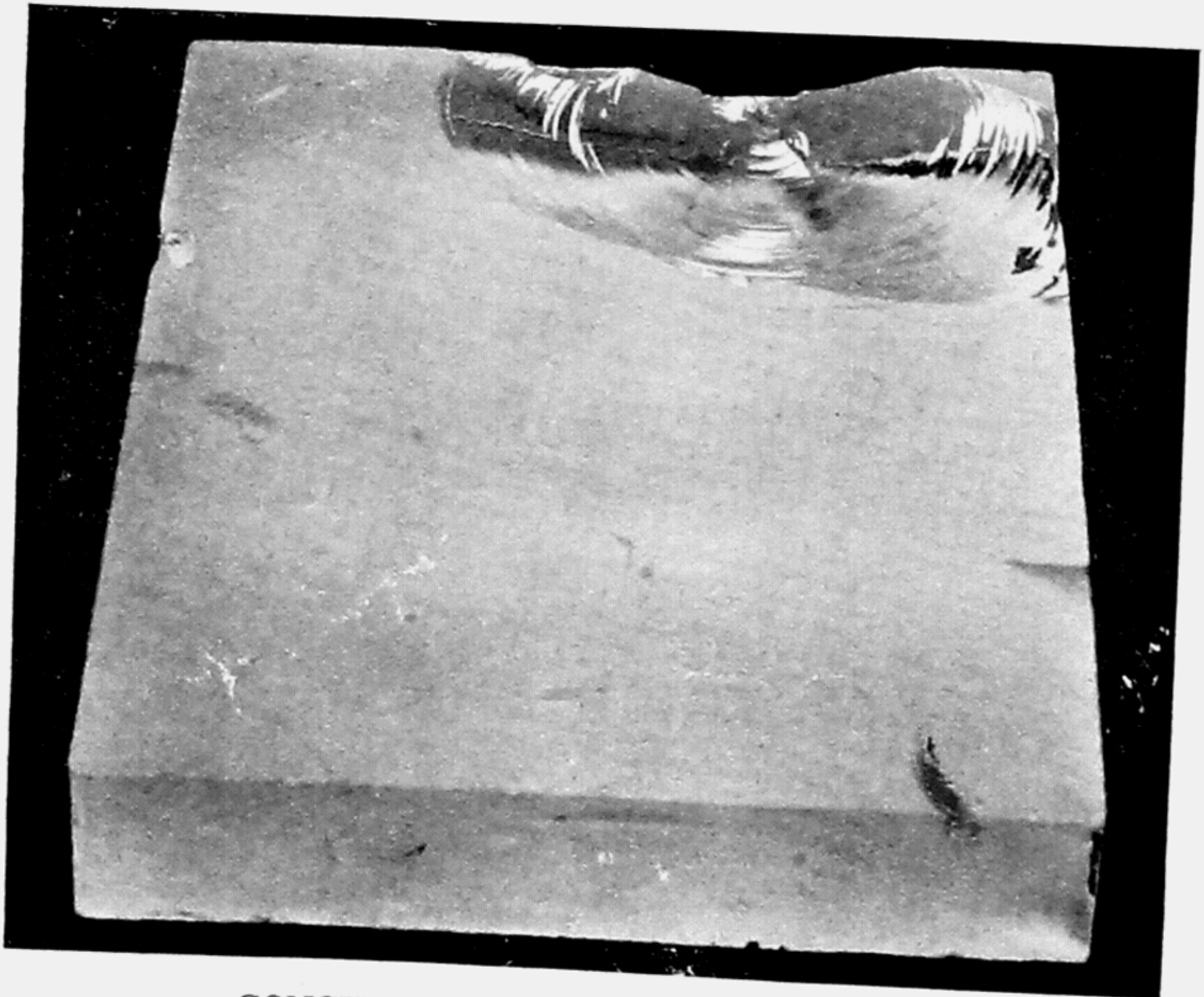
## PART ONE

L. J. M. COLEBY

May 1940



DEVITRIFICATION TAKING PLACE IN COMMON GLASS.  
SILICA PARTICLES CRYSTALLIZING OUT IN THE GLASS.



CONCHOIDAL FRACTURE OF GLASS  
(See page 159)

# GENERAL SCIENCE

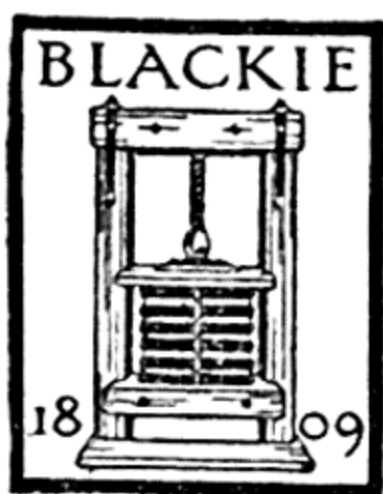
BY

L. J. M. COLEBY

M.A.(Cantab.), Ph.D., M.Sc.(London)

Senior Science Master, County School for Boys, Gillingham, Kent

## PART ONE



BLACKIE & SON LIMITED

LONDON AND GLASGOW

BLACKIE & SON LIMITED  
*66 Chandos Place, London*  
*17 Stanhope Street, Glasgow*

BLACKIE & SON (INDIA) LIMITED  
*Warwick House, Fort Street, Bombay*

BLACKIE & SON (CANADA) LIMITED  
*Toronto*

*First Issued June 1940*  
*Reprinted 1942, 1945, 1946*

*Printed in Great Britain by Blackie & Son, Ltd., Glasgow*

## PREFACE

---

This, the first of two books, covers the first two years' work of a School Certificate course in General Science.

There can be little doubt but that General Science is becoming an increasingly popular subject in our schools. There is sometimes, however, a tendency to lose the science in the generality, and the fundamental elementary principles of the various sciences may be too superficially treated, if not altogether ignored. Scientific principles are more important than their practical and everyday applications, and, useful and interesting as these may be, they should not form the main object of study.

Nevertheless, it is fairly obvious that as an examination subject General Science tends to become more and more a test, not only of an official syllabus, but also of a candidate's general knowledge. It is desirable, therefore, that, in addition to working through such a Course as this, classes should be given day-by-day opportunities of explaining, in clear language, any little scientific problems that may arise, say, in Geography, in ordinary household affairs (water-supply, heating, lighting, etc.), points of interest in the garden or in the streets, discussions in newspapers, and so on—points which often arise as applications of principles formally taught.

In order that the whole of the prescribed field may be covered, it has sometimes been found necessary to curtail the amount of practical work done by the pupils themselves, replacing it by lecture demonstrations. A good

deal of the value of individual work lies in the discipline of the notebook. It is desirable, therefore, that pupils watching a demonstration experiment should have their note-books with them to record observations and readings, and that they should subsequently write the experiment up in just the same way as if they had performed it themselves.

A number of questions from School Certificate papers in General Science have been included in the questions at the end of each chapter. While the wording of these may in some cases present a little difficulty to younger students, it is advisable to keep in mind the standard to be aimed at, for many of the subjects dealt with will not again be considered until the final revision.

In the preparation of this Course I have received many helpful suggestions and criticisms, and I should like to express my appreciation of the valuable help given to me by Mr. F. W. Westaway, and by Mr. W. E. Summerhays, B.Sc., Mr. A. J. Woodcock, M.Sc., and Mr. W. F. Spinks, M.A., who have read sections of this volume in draft. For the X-ray photograph of the hand I am indebted to Dr. J. Dunbar. The crystal photographs are reproduced by kind permission of the Trustees of the British Museum (Natural History), and the photographs illustrating conchoidal fracture and devitrification of glass have been kindly supplied by Messrs. Chance Bros. School Certificate examination questions have been reprinted by permission of the Central Welsh Board and of the Senate of the University of London.

L. J. M. C.

GILLINGHAM,  
*May, 1940.*

## CONTENTS

---

CHAP.		Page
I.	FLOWERING PLANTS - - - - -	1
II.	THE EARTHWORM - - - - -	21
III.	SIMPLE MEASUREMENTS ✓ - - - - -	26
IV.	INTRODUCTORY HEAT ✓ - - - - -	38
V.	INTRODUCTORY LIGHT ✓ - - - - -	69
VI.	DENSITY AND FLOTATION ✓ - - - - -	92
VII.	FLUID PRESSURE - - - - -	107
VIII.	THE DEVELOPMENT OF THE GREEN PLANT - - - - -	128
IX.	THE DEVELOPMENT OF THE FROG - - - - -	140
X.	WATER, SOLUTION, CRYSTALS - - - - -	148
XI.	SOME SIMPLE ORGANISMS - - - - -	164
XII.	MECHANICS - ✓ - - - - -	180
XIII.	THE SKELETON ✓ - - - - -	208
XIV.	AIR AND BURNING ✓ - - - - -	220
XV.	HYDROGEN AND THE COMPOSITION OF WATER - - - - -	237
XVI.	SOME SIMPLE CHEMICAL THEORY - - - - -	247
XVII.	CARBON DIOXIDE. RESPIRATION ✓ - - - - -	260
XVIII.	RESPIRATION AND THE CIRCULATION OF THE BLOOD ✓ - - - - -	268
XIX.	THE WORK OF THE GREEN PLANT ✓ - - - - -	283
	INDEX - - - - -	294

## PLATES

---

	Facing Page
DEVITRIFICATION IN COMMON GLASS: CONCHOIDAL FRACTURE OF GLASS - - - - -	<i>Frontispiece</i>
SOME CRYSTALLINE MINERALS - - - - -	162
PHOTOMICROGRAPHS SHOWING THE CELLULAR STRUCTURE OF PLANT AND ANIMAL TISSUES - - - - -	170
X-RAY PHOTOGRAPH OF A HAND - - - - -	214



THE PAPER AND BINDING OF THIS  
BOOK CONFORM TO THE AUTHOR-  
IZED ECONOMY STANDARDS

## CHAPTER I

### FLOWERING PLANTS

There are some plants that do not form flowers at all. Mushrooms, toadstools, ferns, and mosses are examples, and we shall meet with others later. The familiar flowering plants of country-side and garden all show a very similar plan, and it is easy to distinguish different parts, or **organs**, each of which has a different function, or work to do, in the life of the whole. These parts are the root, below ground, and the shoot or stem, the leaves, and the flowers, above ground.

#### **The Shepherd's Purse.**

This is a small weed which grows very rapidly and is found in waste spaces almost everywhere. Pull up a plant carefully so as not to break the roots, and wash the latter free from soil with a little water. The underground part of the plant is the root system and consists of a main root, or **tap-root**, cylindrical in shape and tapering towards the end, from which arise a number of smaller secondary roots, which in turn branch to form still smaller rootlets. The tap-root grows vertically downwards, unless it is forced to change its direction by stones or other obstacles, but the secondary roots grow in a more or less horizontal direction. The root of a plant has two functions: (1) to anchor the plant firmly to the ground, and (2) to absorb from the soil water, in which is dissolved small quantities of certain other substances essential to the growth of the plant.

The **stem** of the plant grows vertically upwards and is green in colour and cylindrical in shape, tapering upwards. Its functions are twofold: (1) to hold up the leaves and the flowers, and (2) to conduct food and water to and from the various parts of the plant.

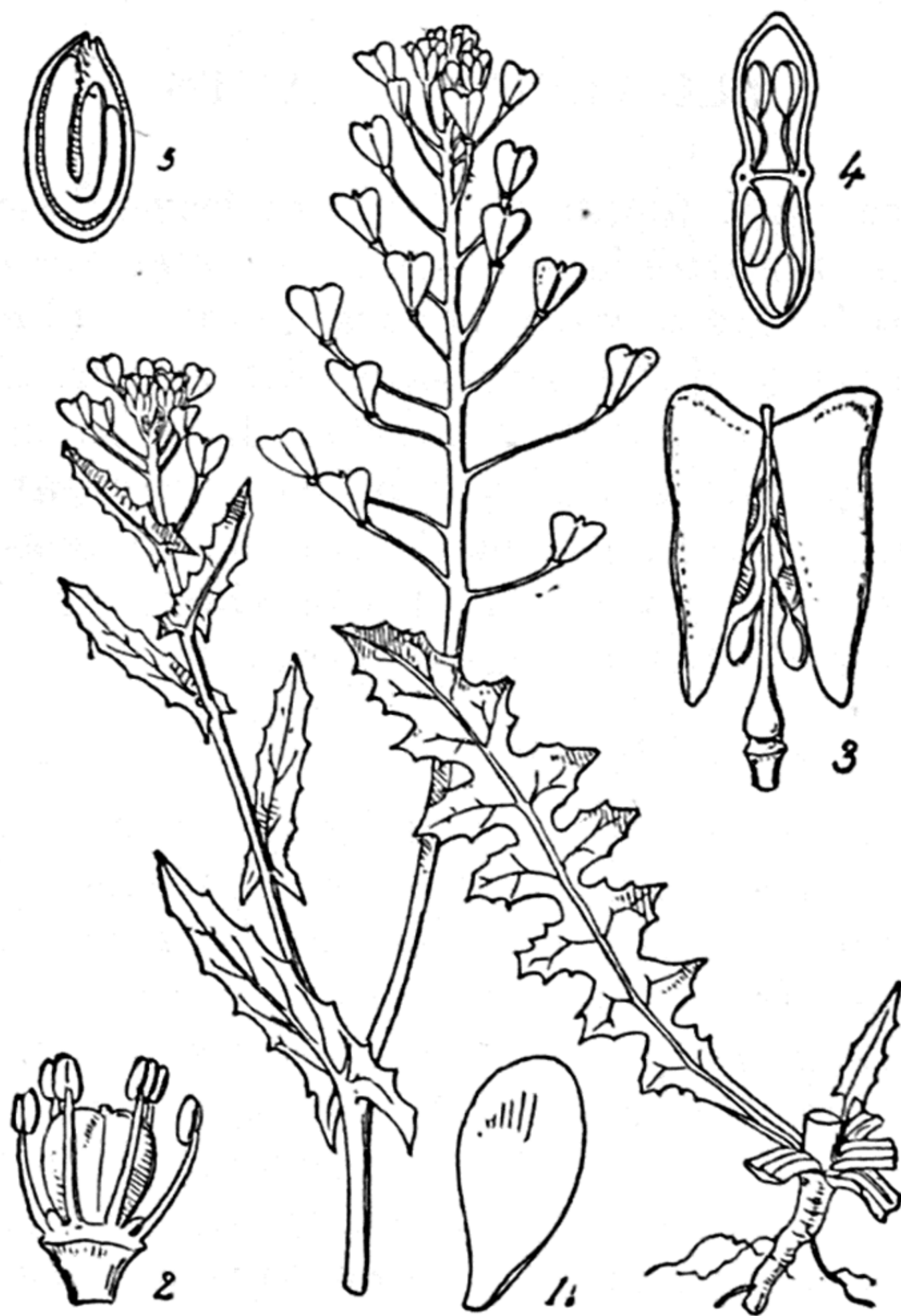


Fig. 1. — The Shepherd's Purse  
1, Petal. 2, Stamens and pistil. 3, Fruit. 4, Cross-section of fruit. 5, Section of seed.

At the base of the stem there is a rosette of **leaves**, differing in shape from the leaves borne higher up the stem. The leaves growing near the root are called **radical** leaves and those higher up **cauline** leaves.

The radical leaves are lobed and wider at the end away from the stem. The cauline leaves are narrow, and widest at the end nearer the stem, where there are two lobes, one on either side, giving the leaf a shape resembling the head of a spear. A vein runs down the middle of each leaf and from this arise at intervals smaller veins on either side, so that the whole of the leaf blade, or **lamina**, is covered with a network of fine veins. The leaves of the Shepherd's Purse have no leaf-stalk, or **petiole**. The function of the leaves is to manufacture food for the plant (see p. 288).

At the top of the stem will be found the **flowers**. Those at the apex, the youngest, will still be in bud. Examine the flower carefully. It is at the end of a short flower-stalk or **pedicel**. The flower itself consists of **calyx**, **corolla**, **stamens**, and **pistil**. The calyx consists of four small green **sepals** which form a protective covering around the flower while it is in bud. Inside the calyx are four white **petals** arranged alternately with the sepals. The petals together form the corolla.

There are six stamens, two short and four long, each consisting of a stalk or filament, at the end of which is a two-lobed **anther** which contains the yellow dust-like **pollen grains**. The two shorter stamens lie opposite each other in the flower and each between two sepals. The four longer stamens are arranged in pairs, opposite to each other, so that the lines joining the two pairs of stamens are at right angles to that joining the two single stamens.

The pistil consists of a flattened hollow box called the **ovary**, which has been formed by the fusing together of two leaves called **carpels**. In the ovary are a number of tiny outgrowths from the inside wall. These outgrowths are **ovules** and eventually develop into seeds. At the top of the pistil there is a short thin **style** which forks out at the top to form two **stigmas**. The

function of the flower is that of reproduction, that is, the formation of new plants. The flower produces seeds which, when conditions are favourable, germinate and grow into new plants.

### The Snapdragon.

Dig up a Snapdragon (*Antirrhinum*), wash its roots free from soil, and examine the different parts of the plant, comparing it with the Shepherd's Purse. The

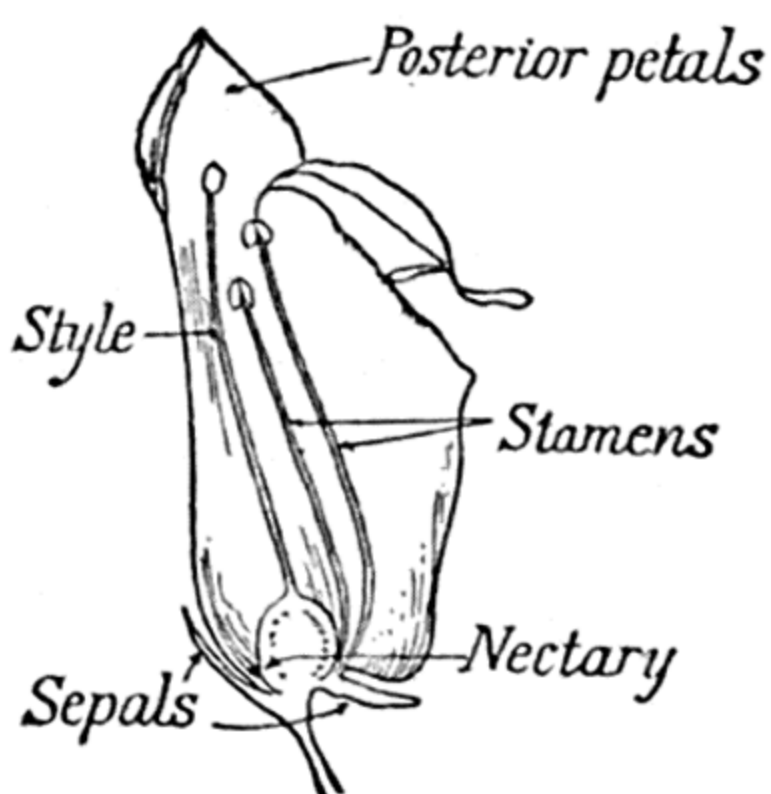


Fig. 2. — Section of Flower of *Antirrhinum*

Snapdragon is a considerably larger plant and the stem is much more branched. The root system is very similar to that of the Shepherd's Purse. There is no rosette of radical leaves. The leaves are dark green in colour, smooth, and narrow, the upper ones being rather narrower than the lower and usually alternate, whereas the lower ones are arranged in pairs on opposite sides of the stem.

The flowers, which are brightly coloured, look at first sight very different from those of the Shepherd's Purse, but if we examine them carefully we shall find that the general plan is very similar, and that, like the Shepherd's Purse, they have calyx, corolla, stamens, and pistil. A single stem carries a large number of flowers, the youngest of which are at the top. The stem, together with its flowers, is called an **infructescence**. Each flower has a short pedicel which arises in the angle or **axil** between a small green leaf, or **bract**, and the stem.

The calyx consists of five green sepals, but these are joined together at their base to form a kind of cup. The brightly-coloured part of the flower consists of

five petals joined together to form a long tube, slightly pouched at the bottom, and downy on the outside. The upper part of the petals form two lips that are firmly pressed together. There are four stamens, two longer than the other two, and the pistil consists of a more or less conical ovary formed from two fused carpels, with its axis set obliquely to the flower-stalk, together with a long curved style ending in a stigma. Round the base of the ovary there is a **nectary**, a gland secreting a sweet juice called nectar.

### **Pollination and Fertilization.**

The ovules of a plant will not develop and ripen into seeds unless a part of their living substance has first fused with, and united with, a portion of the living substance of a pollen grain. Since the ovules are hidden away inside their protective covering of the ovary wall and the pollen grains are formed on a different part of the flower, this clearly presents a difficulty. The first step is the transference of the pollen grains from the anthers to the stigma. This process is called **pollination**, and is brought about in various ways. Once the pollen grain has fallen on the stigma, which generally has a rough sticky surface to prevent the grain falling off, the pollen grain starts to germinate and forms a tiny tube which grows right down the style into the ovary, entering an ovule by way of a small opening called the **micropyle**. Part of the living matter of the pollen grain passes down this tube and, entering the ovule, fuses with part of the living matter of the latter. This fusion of living material is called **fertilization** and takes place **after** pollination.

When a flower has been pollinated by pollen from its own anthers it is said to be **self-pollinated**. When the pollen has come from another flower we have **cross-pollination**. Some plants, including the Shepherd's Purse, are usually self-pollinated, but as cross-pollina-

tion appears to lead to better seeds most plants endeavour to secure cross-pollination. The commonest method employed is for the anthers and pistil of a given flower to ripen at different times. Usually, as in the Snapdragon, the anthers ripen before the stigma and have scattered all their pollen before the stigma is ripe to receive it. Occasionally, the stigma ripens first and has withered before the anthers scatter their pollen. In some plants where the stigma ripens first, it remains receptive to pollen grains sufficiently long to enable it to be self-pollinated if it has not previously been cross-pollinated.

When the pollen grains are ripe the anthers burst open and the pollen grains escape. The slightest movement of the anthers suffices to scatter some of the pollen over the stigma of the same flower. Self-pollination, therefore, is very certain and easy. Cross-pollination is effected either by wind or by insects. Wind-pollinated flowers produce large quantities of very dry, light pollen, readily carried by the wind, and the stigmas of these flowers are usually large and often feathery, so as to have a large surface on which to catch the pollen. Since such flowers have no need to attract insects, they are frequently small and inconspicuous, and produce no nectar. The flowers of a number of wind-pollinated trees, such as the poplar, birch, and hazel, ripen before the leaves appear. This is advantageous since otherwise much of the wind-blown pollen would be intercepted by the leaves.

The Snapdragon is an example of an insect-pollinated flower. An insect visiting a Snapdragon flower whose pollen is ripe carries away with it numerous pollen grains sticking to its body and, if it subsequently visits another Snapdragon flower with a ripe stigma, some of these pollen grains are transferred as the insect's body comes in contact with the stigma. Insect visitors are attracted to flowers for the nectar they contain, and such

flowers are usually brightly coloured and conspicuous, so that the insects may see them easily. They are often strongly scented as well. Many insect-pollinated flowers are so shaped that they are visited only by those insects whose shape and size render them most likely to transfer pollen grains from the anther of one flower to the stigma of another. The Snapdragon is pollinated by humble-bees, whose weight is sufficient to enable them to force open the tightly-closed lips of the flower, and whose proboscis is long enough to reach right down to the nectar at the base of the ovary. Smaller bees cannot enter, at any rate not until the flowers have grown older, when the lips part slightly.

Red clover is another flower pollinated by humble-bees. When red clover was first introduced into New Zealand it failed to produce seed, and this was found to be due to the fact that there were no humble-bees in New Zealand. Humble-bees were therefore introduced, and, with their aid, good yields of seed were subsequently obtained.

From what we have said above it will be clear that the stamens and the pistil are the only **essential** parts of a flower, and in some wind-pollinated flowers both calyx and corolla are absent. Some plants produce two kinds of flower, one with a pistil but no stamens and the other with stamens but no pistil. Examples of these are the Hazel (fig. 3), Oak, and Sycamore. In the case of the Willow, Poplar, Hop, and other plants, a given plant will produce only pistillate (female) flowers or only staminate (male) flowers. Such a plant is said to be **diœcious**.

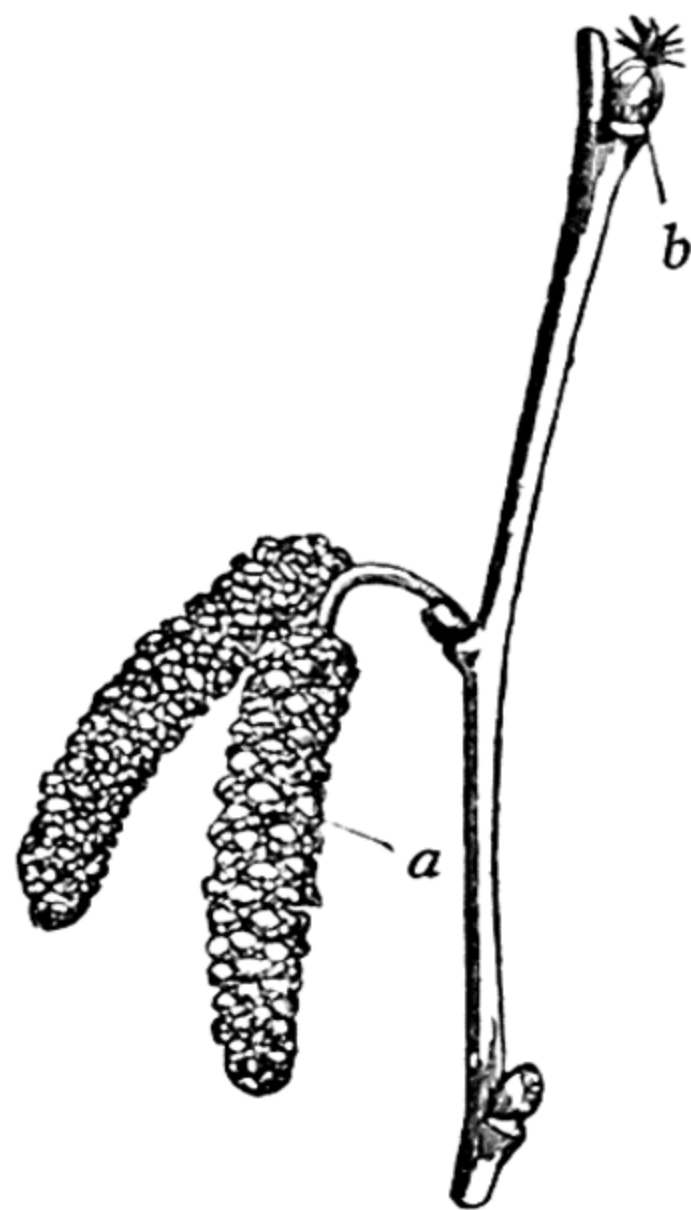


Fig. 3. — Flowers of Hazel

(a) Male; (b) Female

## The Formation of Fruits.

After a flower has been fertilized a number of changes occur. The seeds begin to ripen, the petals, stamens, and style, having done their work, generally drop off, and the walls of the ovary enlarge and often undergo considerable change, forming the **pericarp** protecting the seeds. As a result of all these changes we get the formation of what is termed a **fruit**.

It is quite easy to follow the development of the fruit in the Shepherd's Purse and in the Snapdragon, for below the flowers in full bloom will be found others that are "over" and have begun to wither, so that we find more and more fully-ripened fruits as we work down the inflorescence.

The fruit of the Shepherd's Purse is small, green, flattened, and rather heart-shaped. The interior is divided into two compartments by a partition, to which the seeds are attached. The fruit dries as it ripens, and eventually the pericarp splits open, leaving the seeds attached to the partition (fig. 1). The Wallflower forms a similar kind of fruit except that it is much longer compared to its width.

In the case of the Snapdragon, the sepals and stamens wither away and fall off, and the ovary develops into a dry single-chambered **capsule**, around the base of which the calyx persists. When the capsule is ripe, three openings or pores are formed near the top (fig. 8).

## Other Types of Fruit.

There is a very great variety of types of fruit. Those we have considered above are dry and also **dehiscent**, that is to say, when they are ripe the pericarp splits open to allow the seeds to escape. Some dry fruits are indehiscent, and the seeds are enclosed in a hard shell into which the wall of the ovary has changed. Examples

of such indehiscent fruits are those of the Hazel (Hazel-nut), Oak (Acorn), Horse-chestnut, Beech, and Sycamore.

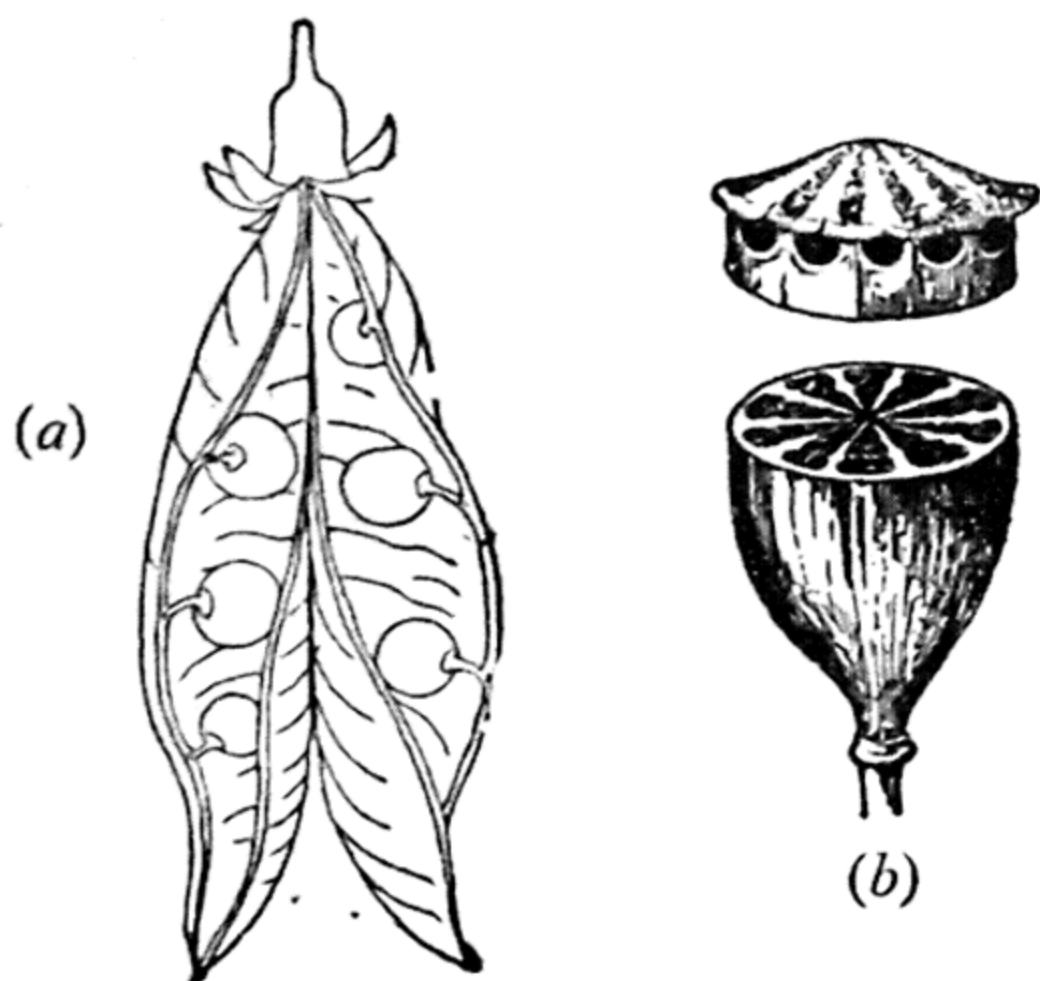


Fig. 4. — Dehiscent Fruits  
(a) Pea; (b) Poppy



Fig. 5. — Hazel Nut  
An Indehiscent  
Fruit

Many other fruits are **succulent** or juicy. Here the pericarp formed from the ovary wall becomes juicy, at any rate in part. Succulent fruits do not dehisce. The pericarp of succulent fruits often consists of several layers. Thus in the plum, we have a skin on the outside, the juicy fleshy part in the middle, and a hard woody stone on the inside. This stone has the seed inside it. The skin, flesh, and stone have all been formed from the ovary wall of the flower. The cherry is a similar kind of fruit, and the gooseberry and the currant differ in having no stony inner layer to the pericarp, the hard pips being the actual seeds.

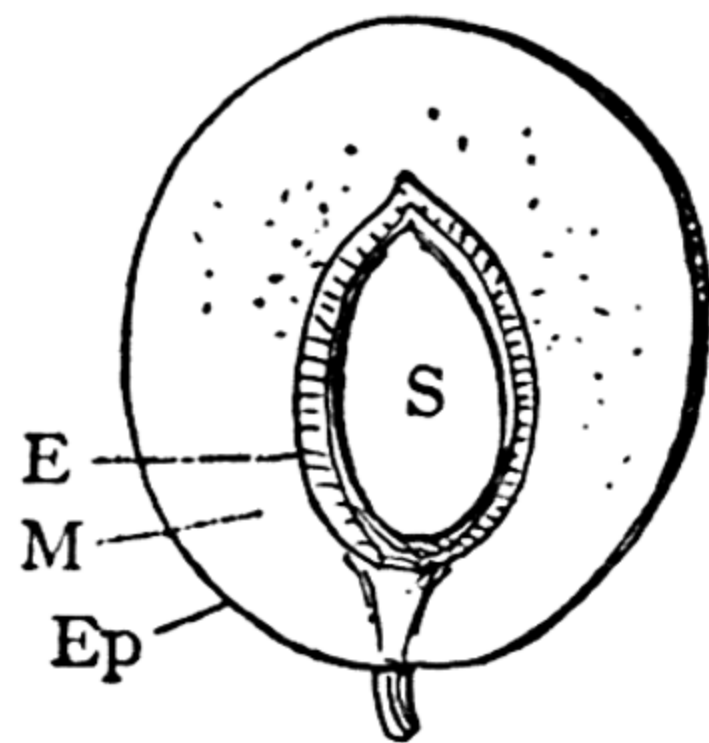


Fig. 6. — Section of  
Plum

S, Seed. E, Hard  
woody stone. M, Soft  
fleshy part. Ep, Skin.

In some succulent fruits the fleshy portion is formed not from the ovary wall, but by the growth of the

**receptacle**, the enlarged end of the flower-stalk which bears the various parts of the flower. In the apple

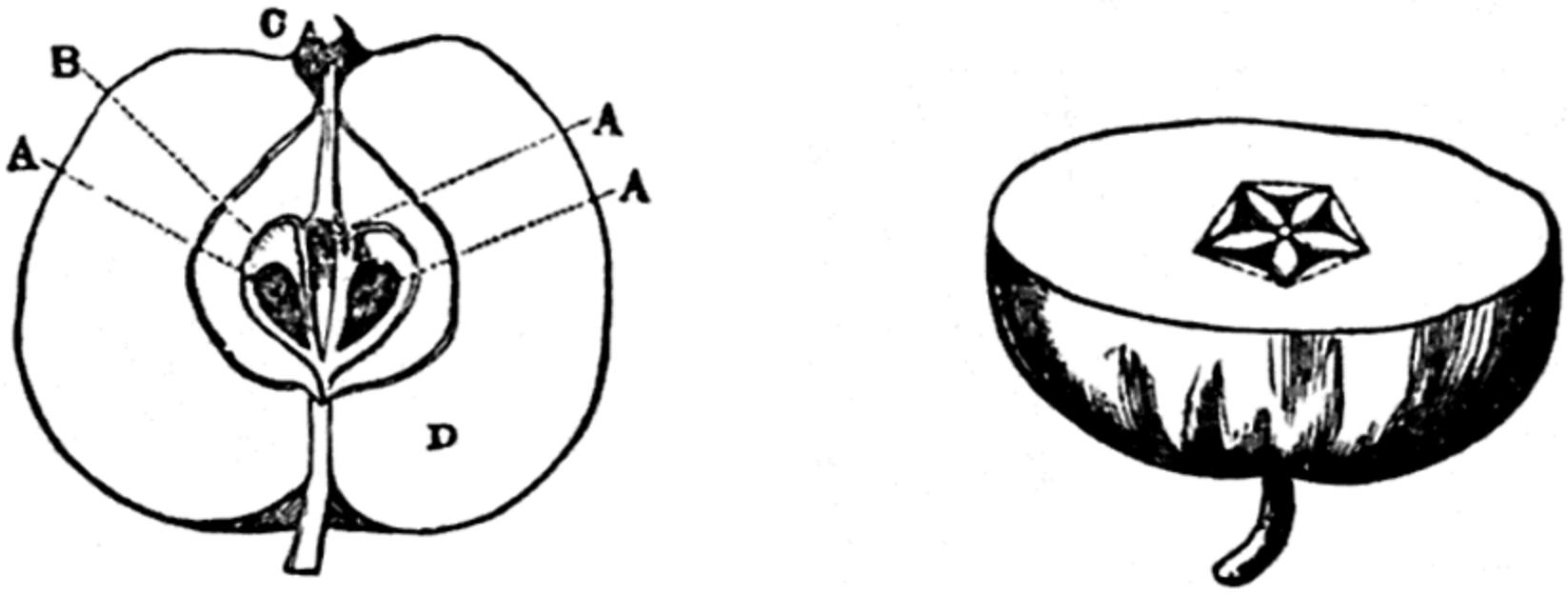


Fig. 7. — The Apple

A, Seeds. B, Carpels. C, Withered calyx-lobes. D, Fleshy receptacle

(fig. 7), the core consists of the pericarp containing the seeds, and the fleshy part is the swollen receptacle.

### Seeds and Seed Dispersal.

A single plant of Shepherd's Purse may produce in one season as many as 64,000 seeds, and many plants produce much larger numbers. If all the seeds produced by a plant merely dropped off when they were ripe they would all fall round the parent plant so closely that the germinating seedlings would be unable to find sufficient soil or get sufficient light to grow, and they would choke each other. Clearly it would be a great advantage if the seeds could be scattered at some distance from each other and from the parent, and, moreover, this might enable a particular kind of plant to gain a footing in places where none of its kind had previously grown.

In the scattering or dispersal of their seeds plants are faced with the same kind of problem as in securing pollination, for the plant itself is unable to move its position. Plants have solved this problem in the same

ways as that of pollination. Plants secure dispersal of their seeds:

- (1) by having fruits which fly open when they are ripe, jerking out the seeds contained in them;
- (2) by means of the wind;
- (3) by means of animals.

In some cases when the fruit splits open part of it may twist or jerk in such a way as to scatter the seeds contained in the fruit. This is often brought about by the unequal drying of different parts of the wall of the fruit, as in the case of the Pea (fig. 4), the seeds of which may be thrown as much as two or three feet.

In the ripe Snapdragon fruit (fig. 8) three pores open near the top. The ripe seeds become detached from their short stalks and lie free in the capsule, to be jerked or catapulted out as the capsule is blown to one side or another by the wind. In the Poppy dispersal is very similar, but in this case a row of pores opens just below the star-shaped stigma (fig. 4). Plants with similar devices include the Campion, Bluebell, Delphinium, Campanula, and many others.



Fig. 8. — Fruit of *Antirrhinum*

Wind-dispersal is a much more effective method. Seeds dispersed by the wind are, as we should expect, usually small and light, and generally have their surfaces increased so that they may be carried more readily by the wind. Examples of this increase in surface are the winged fruits of the Sycamore and the Ash (fig. 9). The former, falling from the tree with a rapid spinning movement, may be carried many yards by the wind before it reaches the ground. The flowers of the Lime (fig. 10) are borne on a stalk which grows from about the middle of the midrib, or main vein, of a long thin green bract. When the seeds are ripe this bract falls off the tree with the fruit.

By far the most successful device to secure wind dispersal is the formation of a parachute of fine downy

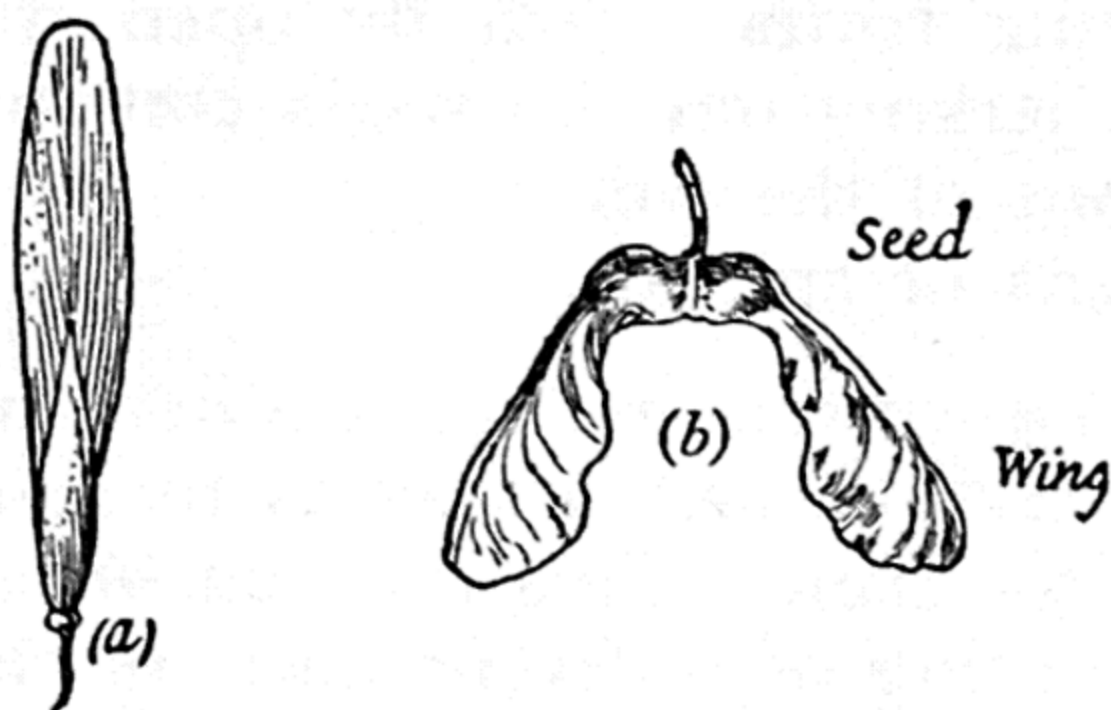


Fig. 9. — Fruit of (a) Ash, (b) Sycamore

hairs. Sometimes the individual seeds have the parachute, as in the Willow Herb (fig. 11) and the Poplar.

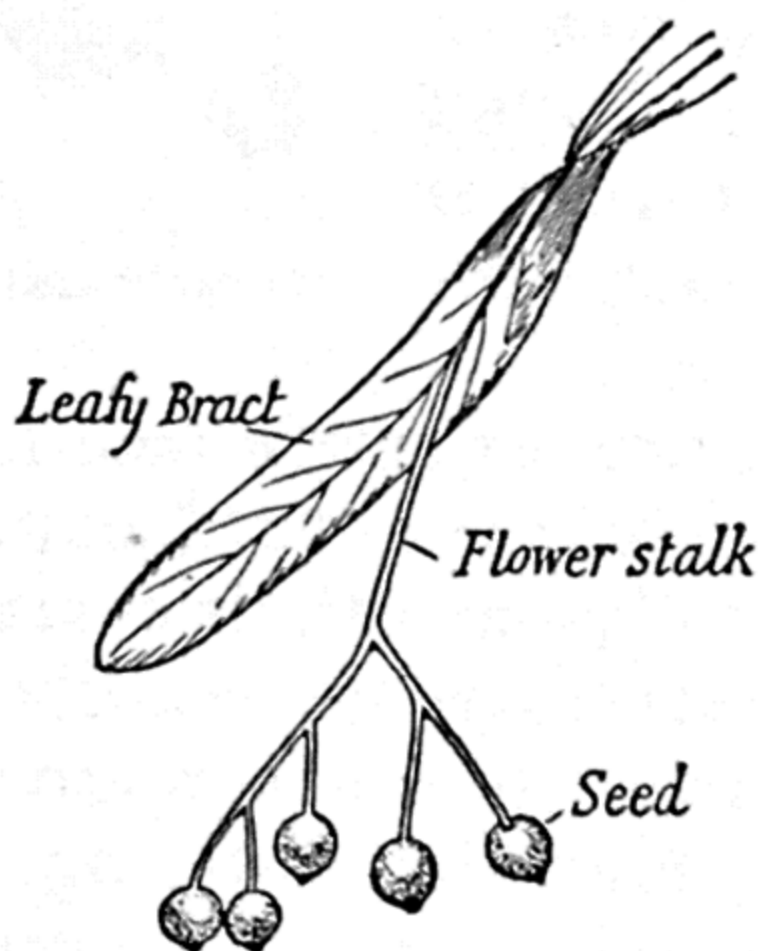


Fig. 10. — Fruit of Lime



Fig. 11. — Fruit of the Willow Herb

Cotton consists of the fibres that form the seed parachutes of the cotton-plant. More frequently the parachute is attached to the whole fruit, as in the Dandelion

(fig. 12), Groundsel, and Thistle. Such fruits and seeds as these may be carried many miles by the wind before they eventually fall to the ground. It is easy to see why a single field or garden in which obnoxious weeds

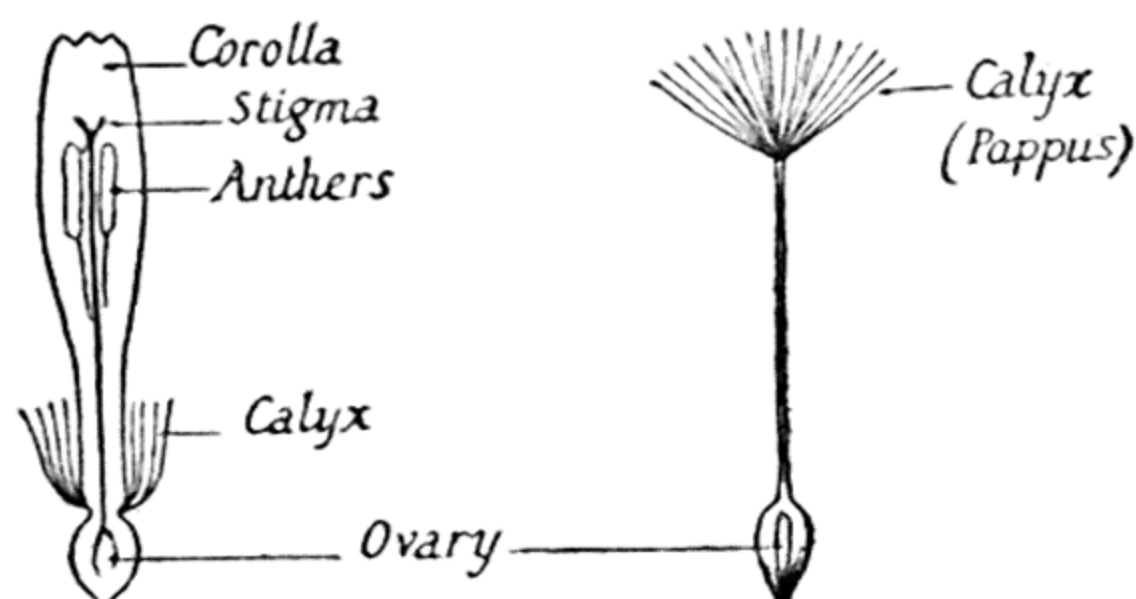


Fig. 12. — Floret and Seed of Dandelion

such as the Thistle are allowed to grow unchecked can act as a centre from which a wide area around may be infected.

Many fruits, like those of the Goose-grass, Bur-

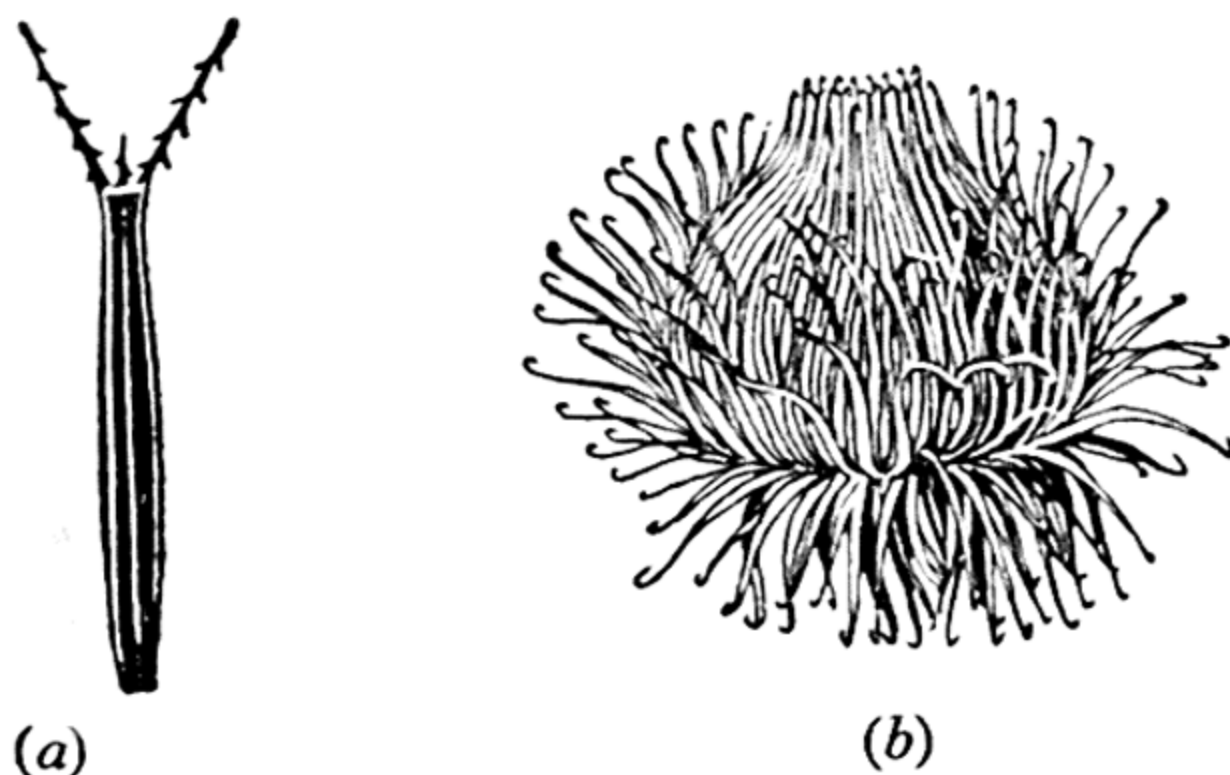


Fig. 13. — Hooked Fruit of (a) Bur-marigold and (b) Burdock

marigold (fig. 13, a), and Burdock (fig. 13, b), have hooks or spikes which catch in the hair or fur of animals that may come in contact with them, and in this way the seeds may be carried considerable distances before falling or being brushed off.

Succulent fruits, such as berries and the like, are attractive to animals and birds, which eat them for food. In their hurry they gulp down with the fleshy part the stones or pips, which, protected from digestion by their hard outer covering, pass through their bodies and fall on the ground with their droppings. A few birds, it is true, such as the sparrows and finches, grind up and actually destroy the seeds, but on the whole birds are very important agents in bringing about the dispersal of many kinds of seeds.

Of the enormous number of seeds produced by a single plant only a few ever grow. The others fail to find suitable conditions for germination. Also, the majority of young seedlings never develop into full-grown plants, for, although seeds can withstand very unfavourable conditions such as cold and drought, young seedlings are easily killed. That is why it is necessary for a plant to produce so many seeds if its kind is to survive, and why it is an advantage for the seeds to be scattered at a distance from the parent plant. The larger the area over which the seeds are scattered the greater will be the chance that some of them, at any rate, will find favourable conditions for germination.

### Winter.

During the cold months of the year conditions are very unfavourable for plant growth. Plants are unable to absorb water from the soil when their roots are numbed by cold, and frost will quickly kill off tender green shoots. Where there is no cold season (and no season without rain) plant growth proceeds the whole year round. Even in many parts of Ireland the winters are so mild that grass grows throughout the year—a great advantage where cattle are reared, since it saves the expense of stall feeding with cattle foods.

Many of our British plants, having set seed, die off completely during the autumn, only their seeds surviving

the winter to germinate when the warmer weather returns in the spring. Such plants, which germinate, flower, fruit, and die in a single growing season, are called **annuals**. The garden Pea is an example of such a plant. The Shepherd's Purse, and a number of other plants, mainly weeds, grow so quickly that they pass through their whole life cycle in a few weeks, and thus there may be two or three generations produced during a single summer. These plants are called **ephemerals**.

Plants like the carrot and turnip germinate in the spring and produce leaves, but do not flower the same year. When the cold weather comes the plant ceases to grow, but is hardy enough to survive the winter. The root contains a considerable quantity of food stored by the plant during the previous summer, and, when the next spring comes, the plant grows very rapidly, flowers, fruits, and finally dies the following autumn. Such a plant is called a **biennial**, because it takes two years to go through its life cycle.

Perennials are plants that live for more than two years. Perennials usually flower each year. The Snapdragon, grown from seed, in the open, does not flower the first summer, but will go on flowering each subsequent summer for years if undisturbed. As a rule, perennials die down and lose their leaves in winter, but the food they have stored in their roots enables them to grow rapidly the next spring.

### **Vegetative Reproduction.**

Although the commonest method by which plants multiply or reproduce is by seeds, it is not the only way, and in fact many common garden plants are rarely grown from seed. In vegetative reproduction a part of the plant other than the seed becomes separated from it and develops into a new plant. A well-known example is the Potato (fig. 14). In the axils of each of the first two leaves formed by the seedling (the **cotyledons**) is

a tiny bud which develops into a stem. These stems, unlike ordinary stems, grow downwards into the ground and hence are called **underground stems**. At the ends of these stems, and on short side stems, there are formed, when the plant is growing vigorously, large swellings called **tubers**, in which is stored food made

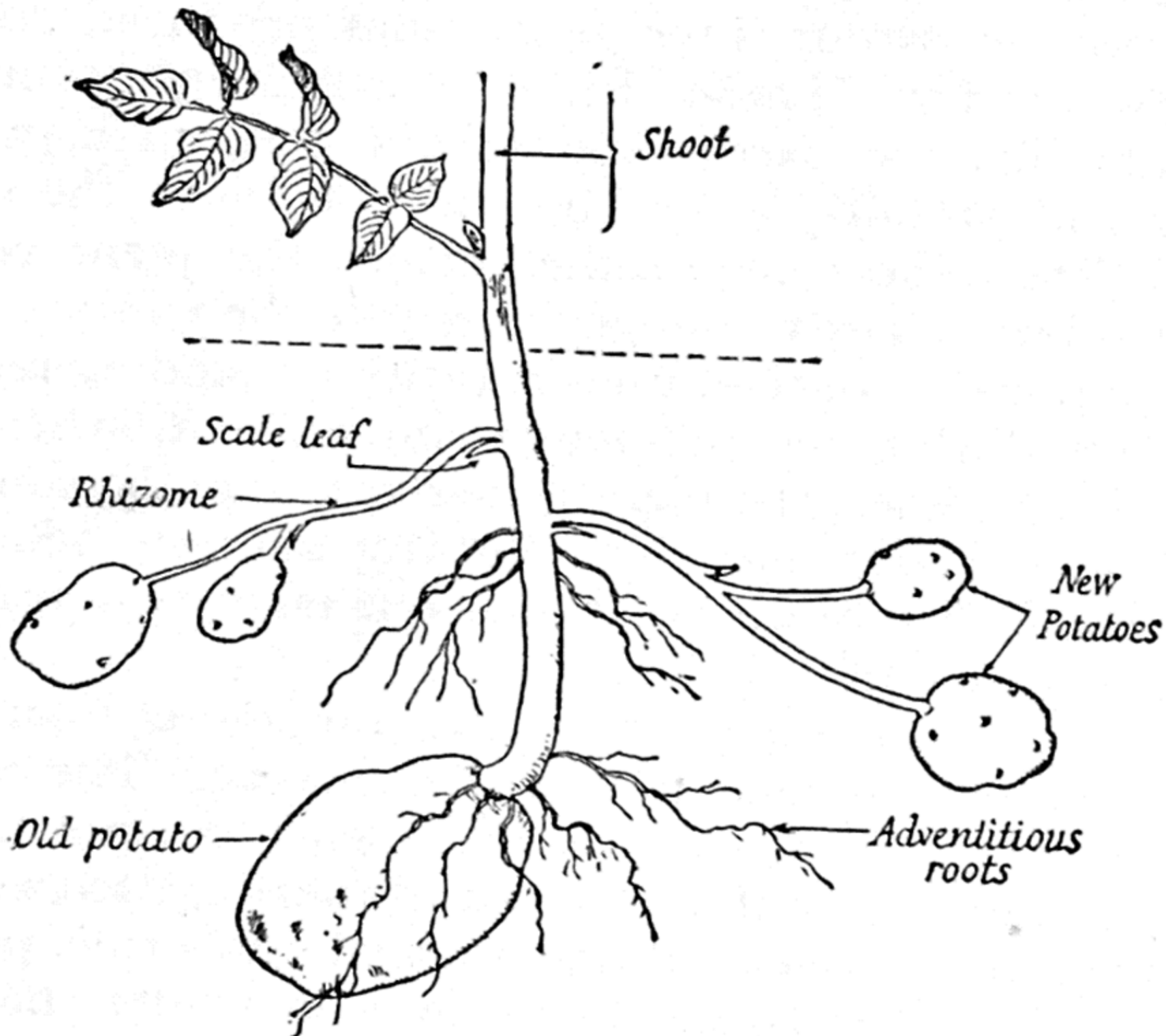


Fig. 14. — Tubers of the Potato

by the plant. When the plant dies in the autumn these tubers become separated from the underground stems, and each is capable of growing into a new plant. A tuber has several buds or "eyes", and these buds are capable of producing a new erect stem. If a large potato is cut into several pieces each piece will produce a new plant, provided that it contains an "eye".

In the Strawberry, buds near the base of the stem produce long side stems which run along the ground. These stems have very long **internodes** between the

leaves and at each internode roots are formed, so that if this creeping side stem, called a **stolon** or **runner**, becomes broken we get two or more completely independent plants (fig. 15). On an ill-kept lawn you will often find clumps of daisies, each with its rosette of leaves close to the ground. If you dig up such a clump and wash the soil away from the roots, you will find that the

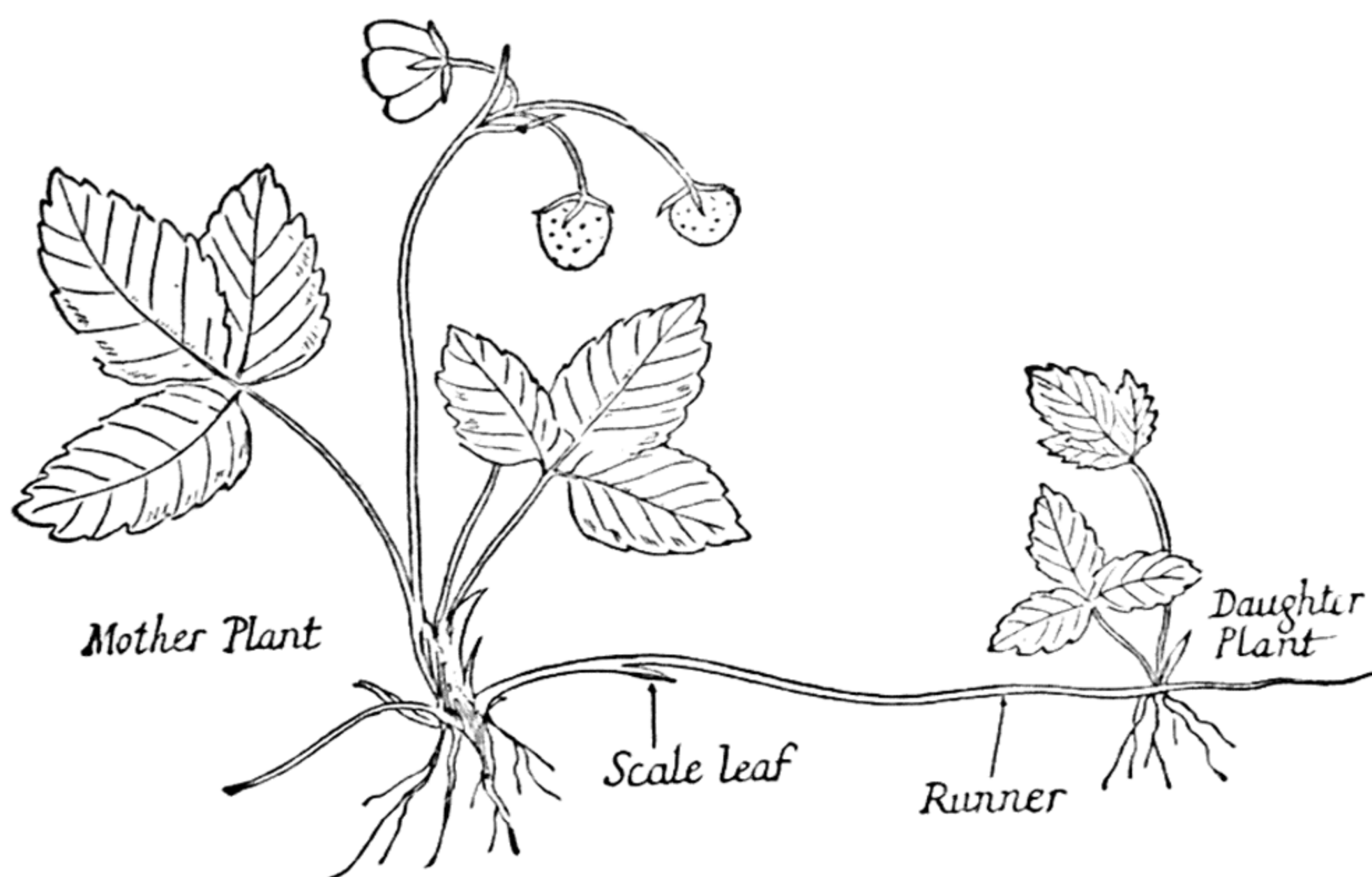


Fig. 15. — Stolon of the Strawberry

individual rosettes are connected by very short runners called **offsets**. We have a somewhat similar arrangement in plants like the Ground Ivy, which has a creeping stem. In this case, it is the main stem that lies along the ground, producing at the nodes side shoots which grow upwards and roots which grow downwards. Sometimes an ordinary erect stem will form roots if it is bent over and pegged down to the soil. This method is made use of in the cultivation of certain plants, especially Carnations.

In many plants the whole of the main stem grows more or less horizontally under ground, forming at the

nodes roots and aerial shoots. Such underground stems are called **rhizomes**, and can easily be distinguished from roots since they bear leaves and buds, which roots

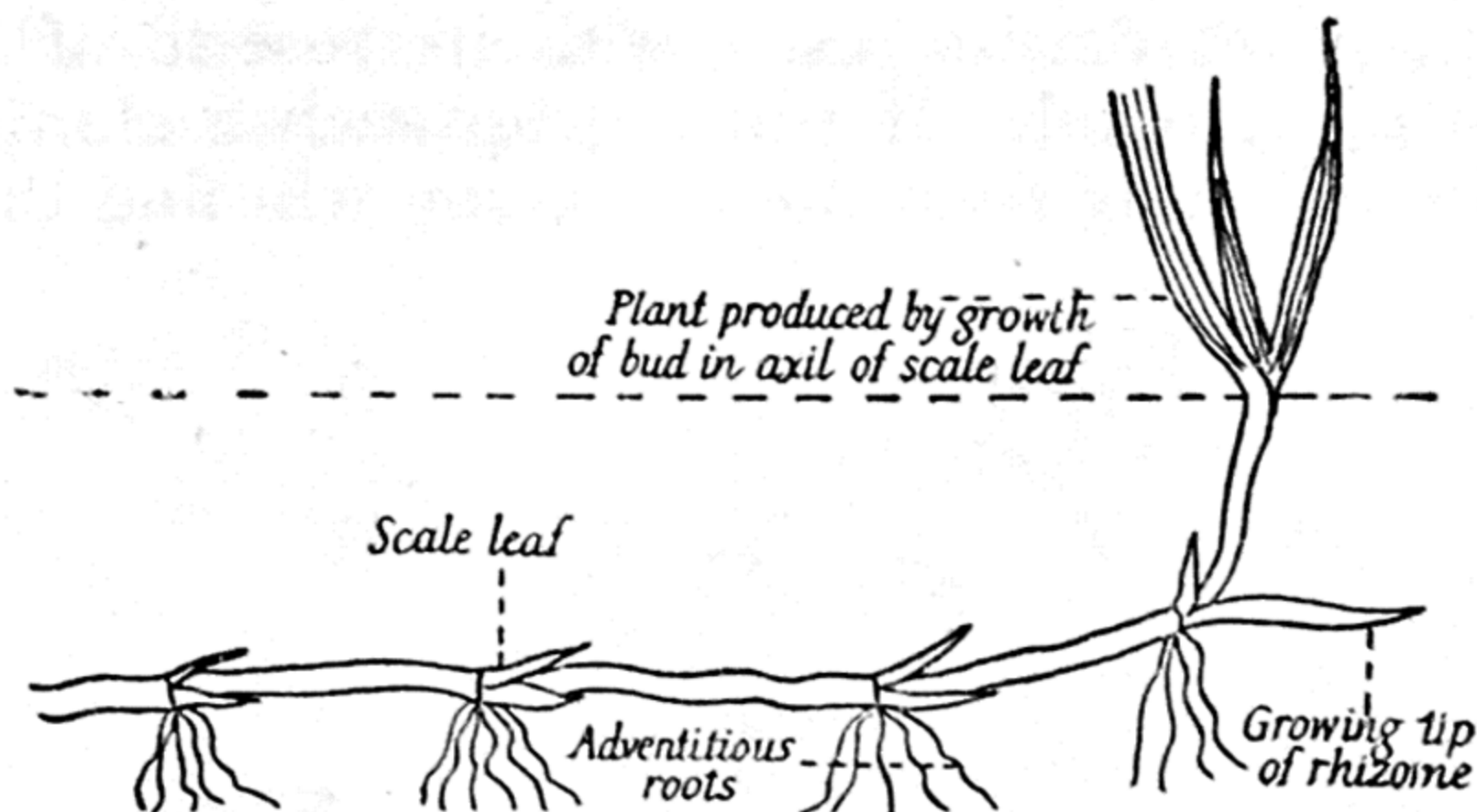


Fig. 16. — Rhizome of Couch-grass

do not. The Couch-grass is a very troublesome weed, for it forms long rhizomes, and if any part of this long underground stem is left in the ground it will continue to grow (fig. 16).

### Bulbs and Corms.

Many plants, and especially those that flower early in the spring, form underground structures called **bulbs** or **corms**, which remain dormant until nearly the end of the winter. A corm (fig. 17) consists of the swollen base of a shoot, surrounded and protected by a covering of scale leaves, and with a bud at its apex. The swollen shoot-base contains a large store of food which enables the plant to grow and flower very rapidly. The leaves continue active in manufacturing food after the flower has died, and the food thus made is stored in a new corm which forms above the shrivelled remains of the old one. When this has been done the leaves die down. Sometimes one or more tiny buds in the axils of the scale leaves develop, as well as the apical bud. When

this happens each of the shoots so formed gives rise to a new corm at the end of the growing season. Corms, therefore, are not only a means of perennation, i.e. of enabling the individual plant to survive the winter, but also, when more than one bud develops, a means of vegetative reproduction.

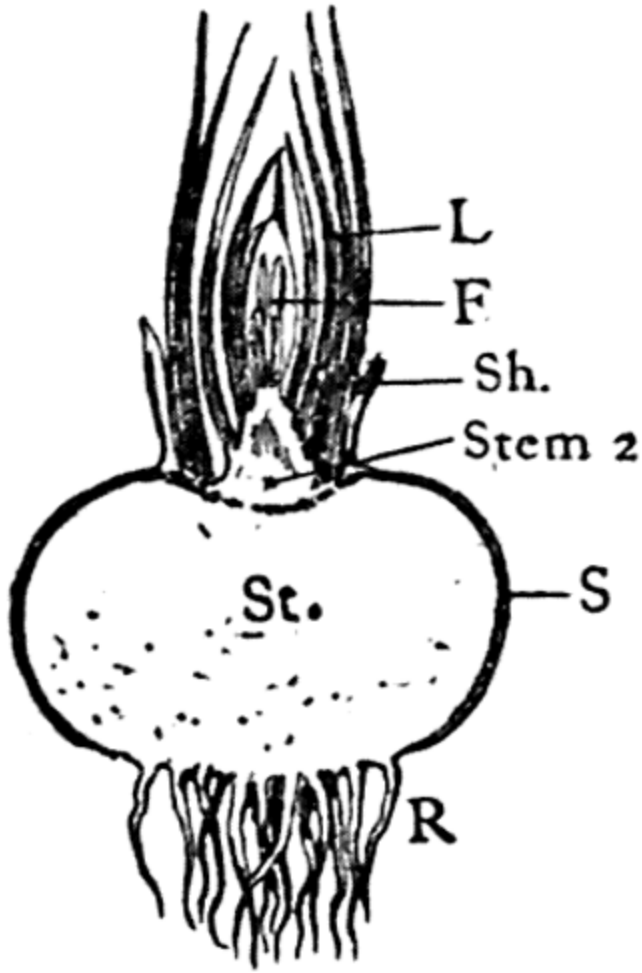


Fig. 17. — Longitudinal Section of Corm of Crocus.

L, Leaves. F, Flower. Sh, Sheathing leaves. St, Stem. S, Brown scale leaves. R, Roots. Stem 2 will be next year's corm.

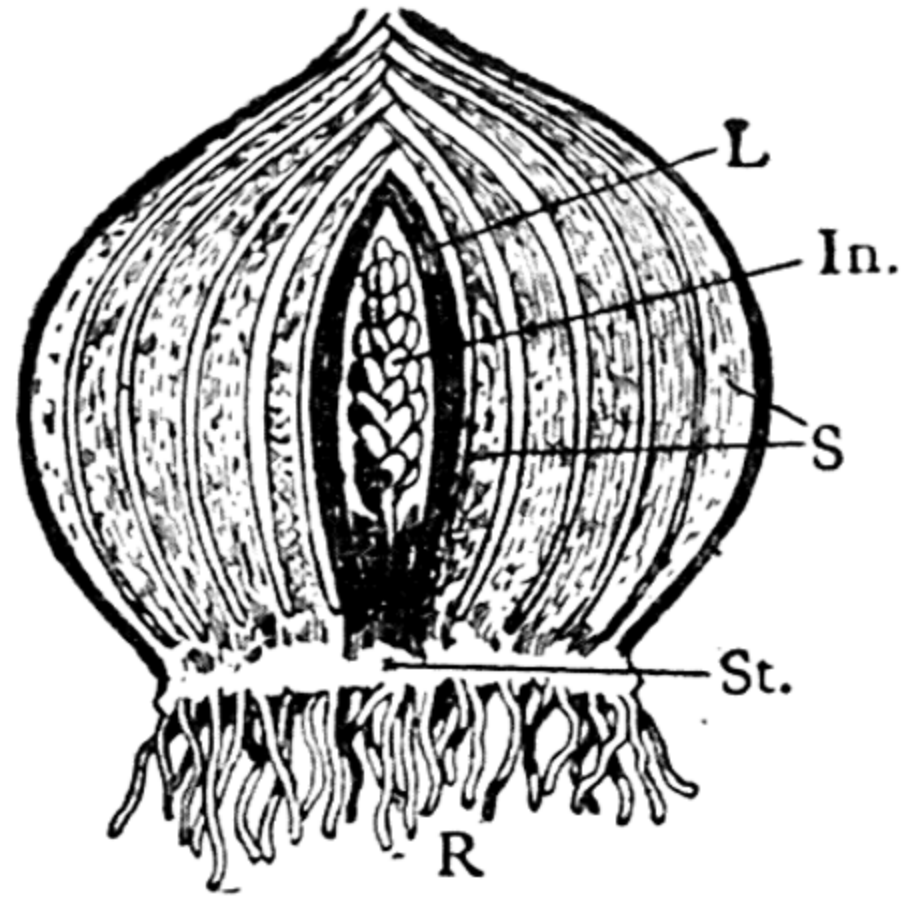


Fig. 18. — Section of Bulb

L, Foliage leaves. In, Inflorescence. S, Fleshy scale leaves. St, Stem. R, Roots.

Bulbs (fig. 18) differ from corms in that the food reserves are stored, not in the swollen base of the stem, but in the swollen bases of the previous year's leaves or in special leaves formed for the purpose. There is a protective layer of tough membranous scale leaves on the outside. More than one bud may develop, so that a bulb, like a corm, serves both for perennation and for vegetative reproduction.

## QUESTIONS

1. Give a brief description of the Shepherd's Purse, mentioning the various parts of the plant, and the work each does in the life of the whole.

2. What are the essential organs of a typical flower? What do you know of their uses? State briefly what happens to each organ as the fruit develops. C.W.B.

3. Define the terms *pollination* and *fertilization*.

C.W.B. (part)

4. What happens to a pollen grain which lands on the ripe stigma of a plant of the same kind?

5. Why do many plants endeavour to secure cross-pollination, and in what ways do they manage it? Refer to plants with which you are familiar.

6. What changes take place as the flowers of (a) the Shepherd's Purse, (b) the Plum, (c) the Apple, ripen into fruits?

7. Why do plants produce so many seeds?

8. What do you mean by *seed dispersal*? By what methods is it brought about?

9. What is the difference between a fruit and a seed? In what ways are animals concerned in the distribution of fruits and seeds? Give examples. L.

10. Give diagrams of four named fruits or seeds which illustrate four different methods of dispersal. State what modification each fruit or seed possesses to assist in the dispersal.

11. In what ways do plants make use of (a) the wind, (b) animals?

12. What is vegetative reproduction? Describe three different methods of vegetative reproduction.

## CHAPTER II

### THE EARTHWORM

On examining an adult earthworm, which is usually about six inches long, we see that it consists of a large number of rings or **segments**, generally about 150, although the number varies. The **anterior** (or front) end of the worm is more pointed than the other (**posterior**) end and on examination with a lens we can see

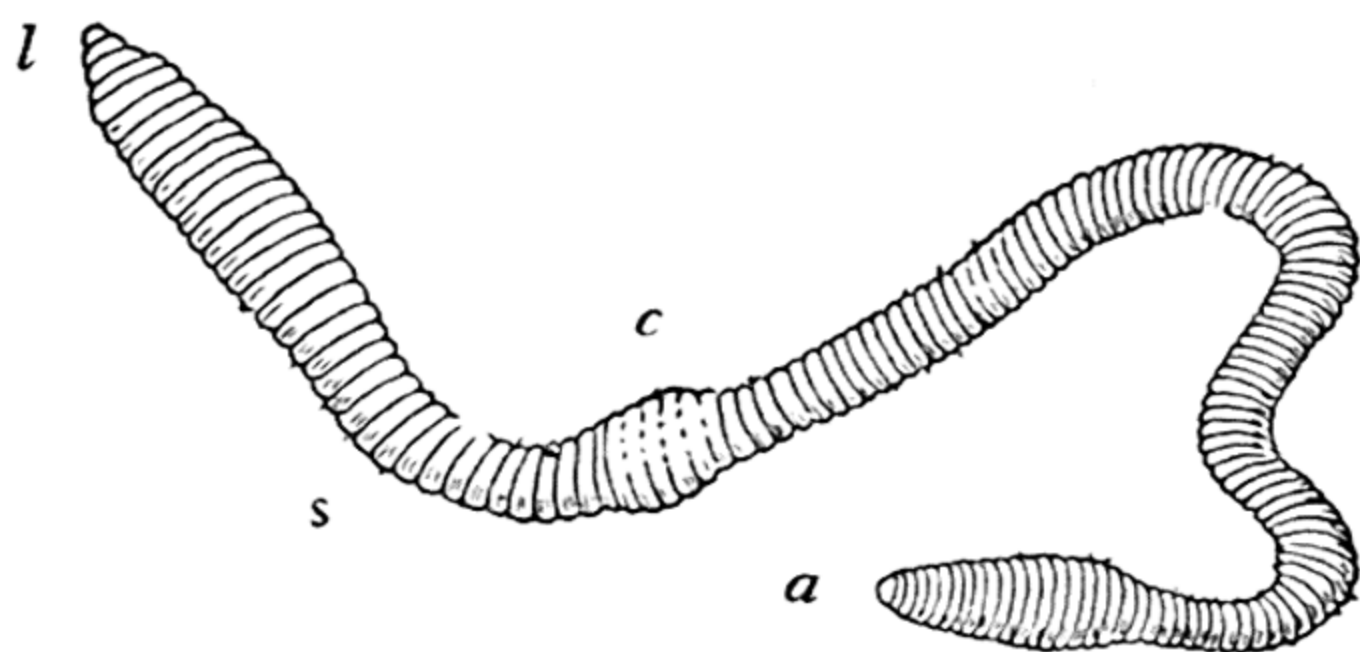


Fig. 19. — The Earthworm

*l*, lips; *s*, setæ; *c*, clitellum; *a*, anus

its mouth with a small overhanging lip. At the posterior end there is also a small opening, called the **anus**, through which is passed waste matter no longer required by the worm. This waste matter consists of undigested food residues together with large quantities of soil from which the food has been extracted. On the lower or **ventral** surface there are four rows of tiny, hard, paired bristles, each bristle curving towards the posterior end of the worm. By means of these bristles, and of muscular

contraction of the front and rear segments alternately, the worm is able to move over the ground. These bristles also enable it to cling tenaciously to its burrow when a thrush or starling tries to pull it out. About a third of the length of the worm from its head (actually the segments 32-37) there is a swelling called the **clitellum**, the function of which will be apparent later. Worms and many other lowly animals have considerable power of regenerating lost parts, and if a worm is cut in two the head part is able to grow a new tail and vice versa.

Earthworms live in burrows in moist earth and come out only at night. Even then part of the worm remains in its burrow, and as a rule, if alarmed, the worm can withdraw into the burrow with astonishing rapidity. Living underground as it does, the earthworm has little need of eyes, and indeed it has none, nor has it any organ of hearing. But although it has no eyes the anterior portion of the worm is able to tell the difference between light and darkness and the worm always seeks the latter. It has a very sensitive sense of touch and is able to feel vibrations through the ground. On a damp summer morning you will often find on a lawn little mounds of fine moist earth called worm casts. Each of these worm casts covers the entrance to a burrow. If you scrape away the cast and stamp on the ground the worm will often come to the surface (thrushes sometimes secure worms in this way). Having caught a worm in this manner you can then proceed to examine its burrow. Near the surface you will find it lined with dead leaves and grass, and farther down it gets larger so that the worm may be able to turn round. In the winter worms go down, sometimes several feet, to get below the depth affected by frost, and there they curl up and sleep until the spring comes.

The earthworm is a vegetarian for preference and eats grass and leaves, but failing these it can live on decaying

vegetable matter which is present in soil (humus). In order to get the latter, however, it has to eat a very large amount of soil, most of which is of no use to it. All this useless matter passes through its body, which extracts such nourishment as it contains, and the residue is passed out through the anus. It is this waste matter that forms the worm casts. It is astonishing what a large amount of soil worms bring to the surface, often from a considerable depth. Charles Darwin, the great naturalist, once calculated that during a year as much as 18 tons an acre may be deposited by worms in this way. As a result of the work done by worms, soil is made more suitable for the growth of plants, for it is drained and aerated (i.e. air is enabled to circulate through it) by the innumerable burrows, and the worm casts themselves form an excellent top soil, for they are rich in mineral substances brought from below. These substances are essential for plant growth, and the amount present in the upper soil tends to get used up. Seeds falling on or being buried by worm casts will germinate readily. The work done by worms is similar to that done by man himself, much less efficiently, with the plough. Unfortunately, the earthworm has enemies that eat it. The mole, burrowing underground, is its greatest danger, and many birds prey on worms they find above ground or partly out of their burrows. Have you ever seen birds following the plough so that they may pounce upon the worms exposed as the soil is turned over?

An adult earthworm produces **eggs** and also male cells or **sperms**, and the eggs cannot develop until they have been fertilized by a sperm that must have come from another worm. Early on a summer morning you may sometimes find two worms lying close together with their ends in their respective burrows. They are **conjugating**. Each worm liberates a fluid containing the sperms from two openings situated on the fifteenth segment and just visible to the naked eye.

This fluid passes from one worm to the other and the sperms are then stored in what are called **spermathecæ**, the openings to which can be seen with a lens between the 9th and 10th and between the 10th and 11th segments. When it is time for the eggs to be laid, the clitellum becomes surrounded with a tough membrane and the worm then proceeds to crawl backwards out of the girdle formed by this membrane. As the membrane passes the 14th segment it receives several eggs through two openings leading from the ovaries where the eggs have developed, and as it passes the openings from the spermathecæ some of the sperms stored there are also deposited in the membrane, the edge of which then curls over to form a closed yellowish cocoon. This the worm leaves on or under the surface of the ground. The sperms fertilize the eggs inside the cocoon but, as a rule, only one of the eggs develops and this eventually hatches out as a small worm.

**Practical Work.**—Examine an adult earthworm, both with the naked eye and with the aid of a small hand lens. Make a careful drawing of all you observe.

Draw a worm slowly backwards across the back of the hand and feel the bristles on its under surface. Place the worm on a sheet of stiff paper and observe the way in which it moves on the surface of the paper. What do you think is the cause of the rustling sound? Put the worm on a sheet of smooth glass. Is it able to move about as easily as on the paper?

Put two or three worms in a box and arrange so that while one part of the box is brightly illuminated the other part is in deep shadow. Note that the worms move to the darkened part of the box and stay there.

Take a 2-lb. glass jam jar. Put a layer of moist earth in the bottom, then a layer of moist sand, and then fill up with moist earth. Put a couple of earthworms in the top layer of earth, cover the outside of the pot with black paper, and leave for a few days. Remove the paper and examine the burrows against the glass. Why was the black paper used? Notice how the layer of sand has been mixed up with the other layers.

Fill two flower-pots with the same kind of moist earth. Put two earthworms in one pot and none in the other, and

leave both pots out of doors for some weeks. Again examine the two lots of soil. Which do you think would be the more suitable for planting seeds in? Why? In this experiment the pot of soil to which we did not add any worms was exactly the same as the other one, and we treated it in exactly the same way except that we did not add the worms. We may therefore reasonably conclude that any differences we find between the two lots of soil at the end of the experiment are due to the earthworms. We have really made two experiments at once. We have observed what changes occur in the pot to which we have added the earthworms and also what changes occur in the pot to which we have not added any earthworms. The second, or control, experiment enables us to find out all the changes that occur except those due to the earthworm. The use of controls is a very common method of experiment, especially when we are dealing with living things.

### QUESTIONS

- ✓ 1. Why are earthworms useful to man?
- ✓ 2. How do earthworms reproduce?
3. An earthworm and a flowering plant, such as the Shepherd's Purse, are both living things. In what ways do they (a) resemble each other, (b) differ from each other?
4. In what ways does an earthworm endeavour to protect itself from birds?
5. Would you expect to find many earthworms in a sandy soil?
6. Why do gardeners sometimes attempt to kill all the worms under a lawn?
7. Calculate the area of your garden, and hence the amount of soil brought to the surface of the garden by worms in the course of a year, assuming Darwin's estimate of 18 tons an acre.

## CHAPTER III

### SIMPLE MEASUREMENTS

✓ In science we are constantly finding it necessary to measure things. Many of these measurements are very difficult to make, but they all depend essentially on the measurement of certain simple quantities such as length, weight, and time.

In order to measure any quantity, for example, a length, we require first of all to have a **unit**. The length of a cricket pitch is 22 *yards*. The unit here is the *yard*. It would be quite meaningless to say that the length was 22. Twenty-two *what?* The statement of a length, as of most other things we measure, involves two terms, a unit, and a number that tells us how many times the unit is contained in the quantity we are measuring.

We may select our own units to start with, but once we have chosen them we must stick to them for a given experiment or series of measurements, although we can change them for another experiment. If we had no ruler, and wanted to measure two lines on a sheet of paper to find which was the longer, we might use our pencil as a unit. One line might be  $2\frac{1}{2}$  times the length of our pencil, and the other 3 times. Obviously, we must use the *same* pencil for both measurements.

The unit of length in general use in this country is called the yard, which is the distance between two gold plugs on a bronze bar, very carefully preserved at the Board of Trade. Since bronze expands when it is heated, it is necessary to specify the temperature at which

the distance is correct ( $62^{\circ}$  F.). Each country decides on its own units and, when these are not the same, considerable difficulty arises in international trade. Most parts of the British Empire use the same units as we do. In the United States, the units, although called by the same names, are not quite the same as ours, although the differences are very small in most cases. 1 American yard = 1.000003 English yards. 1 English gallon = 1.20094 American gallons.

The majority of the other countries of the world have adopted a uniform system of weights and measures called the **Metric System**. The unit of length in this system is the **metre**, which is equal to 39.37 inches. Once a unit has been decided upon, larger and smaller units can be obtained by multiplication or division. Thus, a **foot** is one-third of a yard, a **mile** is 1760 yards, and so on. The great advantage of the metric, or decimal, system is that the various units derived in this way are all obtained by multiplying or dividing the original unit by 10 or powers of 10. Thus, 1 decimetre =  $\frac{1}{10}$  metre, 1 centimetre =  $\frac{1}{100}$  metre, and 1 kilometre = 1000 metres. The metric system is universally employed in scientific work throughout the world, except in engineering.

Straight lengths are usually measured by means of a straight scale such as is found on the ordinary school ruler. But for greater accuracy, and in some special cases, various other forms of apparatus are used.

### The Vernier.

When we attempt to measure a line, we rarely find that its length is an exact number of the smallest units marked on our scale. } Thus in fig. 20 FE is more than 1 unit and less than 2. { The fraction of a unit may be estimated by eye, but by using an additional scale called a **vernier** we can obtain the decimal place with accuracy. The vernier scale is so constructed that 10

divisions on the vernier scale (CD) are equal to 9 divisions on the main scale (AB).] To use the vernier scale, look

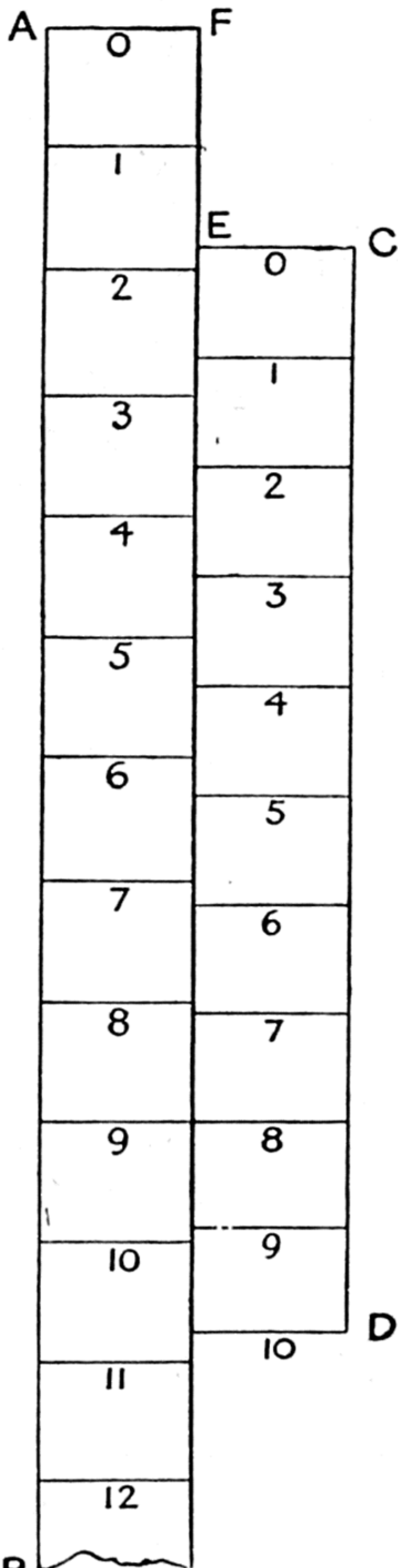


Fig. 20. — Vernier Scale

along it until you see one of the divisions coinciding with one of the divisions on the main scale. Suppose it is the 8th vernier division that coincides. Then the required decimal place is  $\cdot 8$ , and the length FE is equal to 1 unit plus  $\cdot 8$  unit, i.e. 1.8 units. If no vernier division coincides exactly with a division on the main scale, the one that does so most nearly is taken.

### The Screw Gauge.

The screw gauge (fig. 21) is used for measuring accurately small lengths, such as the diameter of a

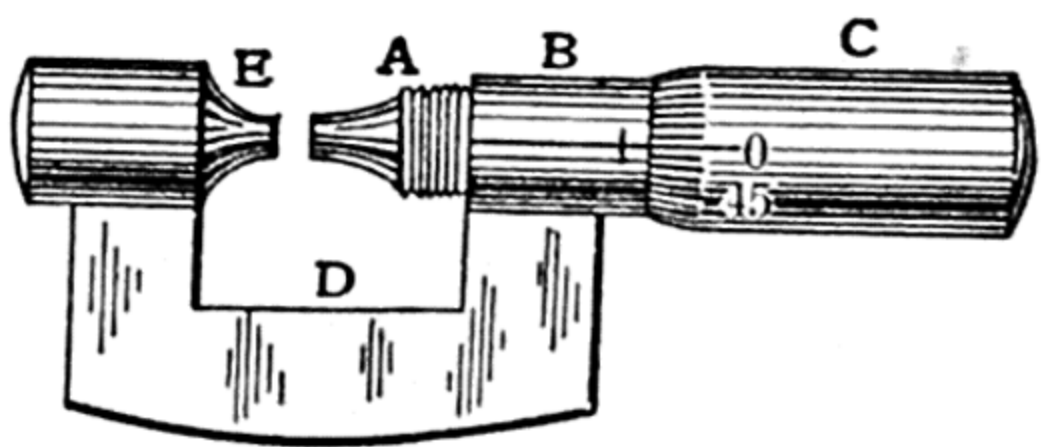


Fig. 21. — Screw Gauge

wire or the thickness of a plate. When the head C of the gauge is rotated through one complete revolution the screw A moves towards E a distance equal to the pitch of the screw, i.e. the distance between consecutive threads on the screw, usually  $\frac{1}{2}$  mm. The head is divided into 50 equal

divisions, so that each of these corresponds to  $\frac{1}{100}$  mm. To use the instrument, first close the screw on to E, *but not tightly*. The zero of the circular scale on the head should now be level with the line marked on the barrel. The screw is then opened and the object to be measured placed between E and A, the screw being closed so as to hold the object gently. The reading along the barrel will give the number of half millimetres, to which must be added the hundredths of a millimetre recorded on the head. Thus: barrel reading 7, circular scale reading 23—length of object equals  $3.5 + 0.23 = 3.73$  mm.

### Calipers.

These are used for measuring the internal or external diameters of cylinders, tubes, etc., and also for finding the thickness of the walls of tubing. To find the external diameter, the tube or cylinder is placed between the tips A of the calipers (fig. 22), and the arms adjusted until the cylinder will just pass through. Distance between the tips is then measured on a scale. The other end B of the calipers is used for the internal diameter, the jaws being adjusted so that they will just slide into the tube. Their distance apart is then measured as before.

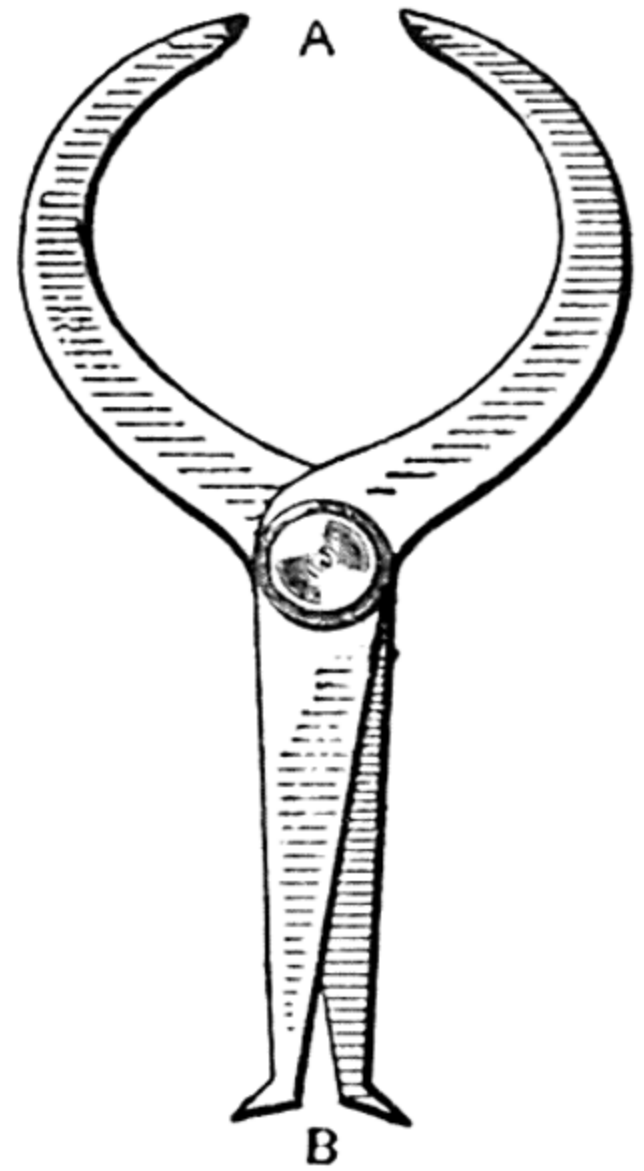


Fig. 22. — Calipers

### The Cone Gauge.

A very quick and simple method for finding the internal diameter of a tube is the use of a **cone gauge** (fig. 23). This is a triangular or conical piece of metal, the base of which is  $\frac{1}{10}$  of its length. It follows from its shape that its diameter at a given distance from the

vertex is  $\frac{1}{10}$  of the given distance. The gauge is inserted into the tube as far as it will go, and this distance is read off. If this is 7.2 cm., then the diameter of the tube is 0.72 cm.

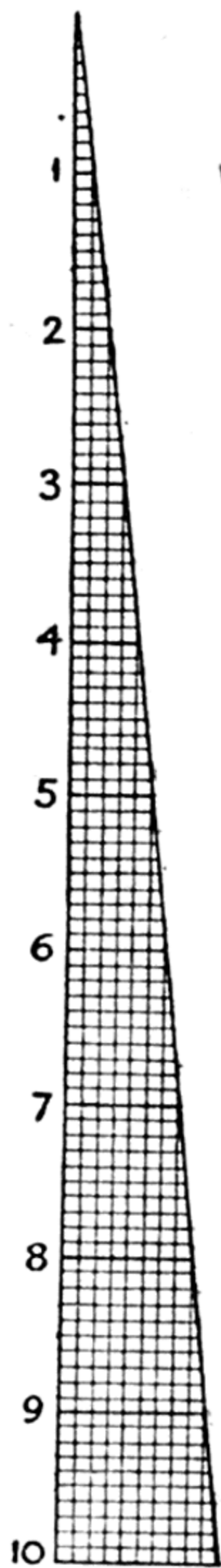


Fig. 23.  
Cone Gauge

## The Measurement of the Volume of Liquids.

**The Measuring Cylinder.** A measuring cylinder (fig. 24) is a tall cylindrical glass vessel, with a spout to facilitate pouring, and with a scale of volume etched on the outside of the glass. Because the scale is on the outside of the glass while the liquid is on the inside, it is necessary to read the scale with the eye at the same level as the liquid surface, otherwise there will be an error in the reading due to **parallax** (fig. 25, and see p. 78). The reading will be too high

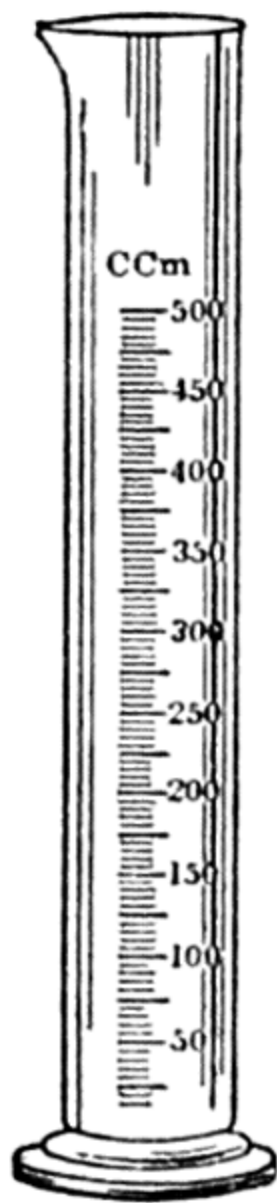


Fig. 24.  
Measuring  
Cylinder

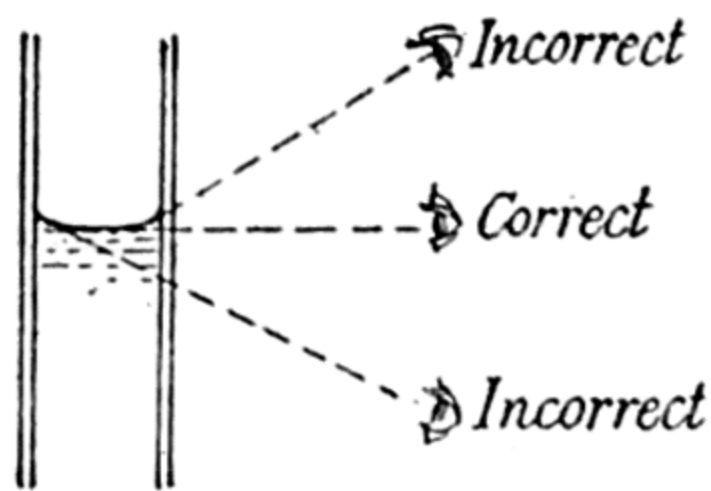


Fig. 25. — How to  
read the level of a  
liquid correctly.

if the eye is above the level of the liquid, and too low if the eye is below the level of the liquid. Measuring cylinders are usually graduated in cubic centimetres (c.c.) or millilitres (ml.). 1000 c.c., or millilitres, equal 1 litre, which is the volume of a cube having an edge of 10 cm.

**The Burette.** Small volumes of liquid can be

measured out more accurately by means of a burette (fig. 26). This is a glass tube graduated in c.c. and tenths of a c.c. from the top downwards, and fitted at the lower end with a tap or a spring clip. The burette is filled with liquid, and a little of the liquid is run out so as to displace the air in the narrow part of the jet below the tap. Suppose the reading of the burette is 5.6 c.c. If we want to measure out 10 c.c. of liquid, we allow the liquid to run out *slowly* until the level reads 15.6 c.c. Remember to avoid error due to parallax by always taking the reading with the eye on a level with the liquid surface. A burette should always be carefully washed out with water after use, as many liquids, if left in contact with the tap, cause it to stick.

**The Pipette.** The measuring cylinder and the burette can both be used for measuring out varying quantities of liquid, but the pipette (fig. 27) is used to measure out one particular volume only — that marked on the bulb — often 20 or 25 c.c. The tip of the pipette is placed under the liquid and the latter sucked up until it stands above the mark A in the stem. Great care must

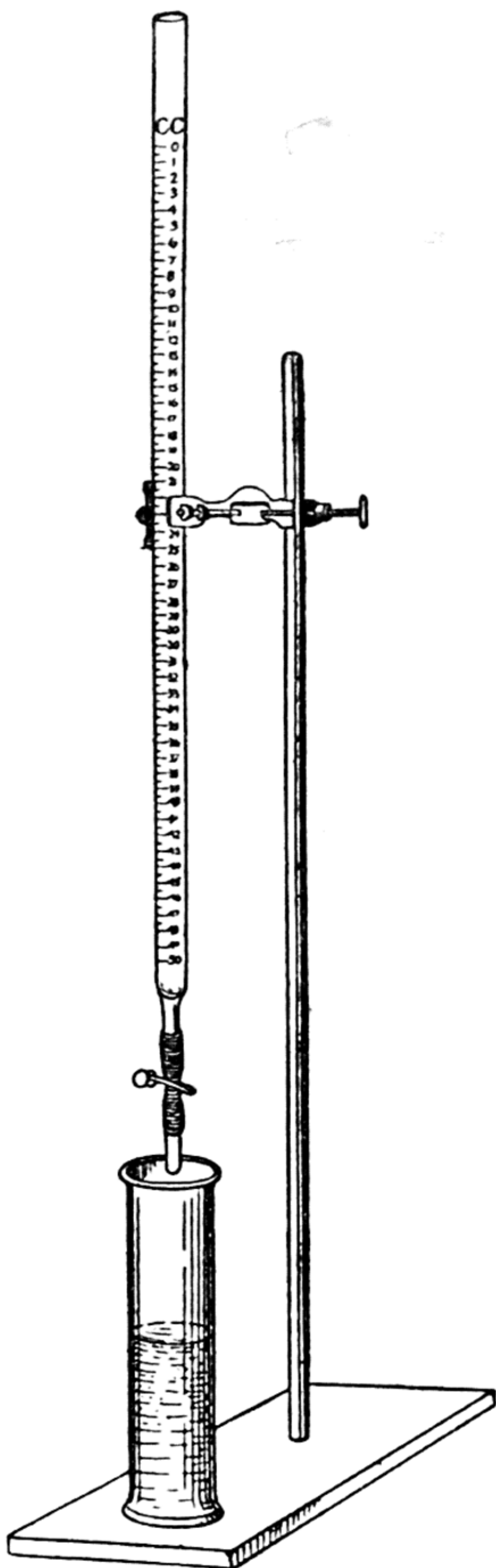


Fig. 26. — Burette

be taken to avoid getting any of the liquid in the mouth. [The end of the stem is then removed from the mouth and the forefinger quickly placed over the top before the level of the liquid has fallen below A. By slightly releasing the pressure of the finger, the level of the liquid can be caused to fall slowly until it is level with the mark, after which, by removing the forefinger, the contents of the pipette can be run out into a vessel.]

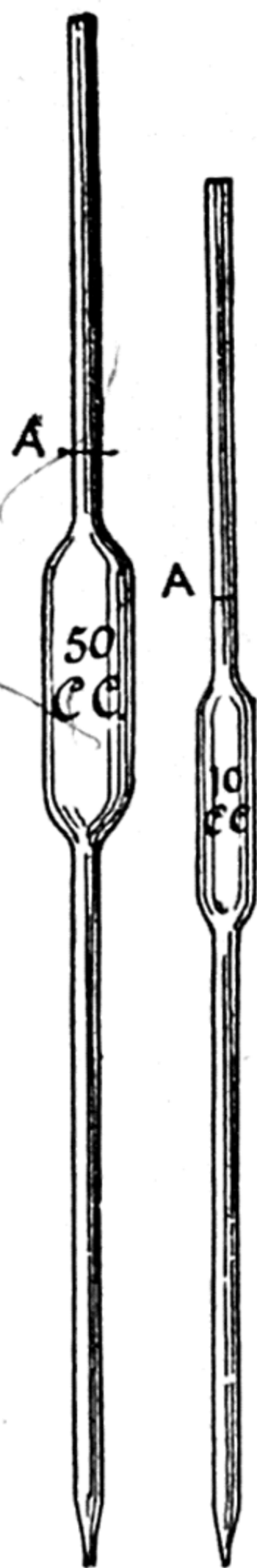


Fig. 27.  
Pipettes

### [The Volume of a Solid.] ✓ P

The volume of regular solids can be found by measuring the length, radius, etc., and then calculating the volume according to the geometrical shape. The volume can also be found, as can the volume of an irregular solid, by using a measuring cylinder, provided the solid does not dissolve in water. A suitable quantity of water is put in the cylinder, and the volume noted. The solid is then immersed in the water, the level of which rises. The difference between the original volume and the final volume recorded by the cylinder is the volume of the solid immersed.] A variation of this is the Eureka can method (see Experiment 20, p. 97), where the water displaced by the solid is caught in a measuring cylinder.

None of these methods is particularly accurate, and the best method of finding the volume of a solid is by the application of Archimedes' Principle (see p. 96).

## The Measurement of Weight.

✓ A quick and easy way of measuring weight is to use a **spring balance** (fig. 28), provided no very great accuracy is required.

For more accurate work we use the **chemical balance** (fig. 29). [This consists of a brass beam A, from which are suspended two scale pans G and H, by means of stirrups F, D, which rest on agate knife-edges (fig. 30). The beam itself is fitted with a knife-edge that rests on a flat piece of agate attached to the top of the pillar B. The purpose of the knife-edges is to make the balance sensitive, that is, to cause a very small extra weight in one pan to produce a noticeable deflection of the beam, and to ensure that the two arms are equal in length. The deflection of the beam is read by means of the long pointer C, attached to the beam, which moves over the scale S. N is a plumb bob which indicates whether the balance is vertical: adjustment can be made by means of the levelling screws O. Agate is exceptionally hard, but even agate knife-edges become worn down in time, causing the balance to stick a little and become less sensitive. To reduce this wear as much as possible the weight of the beam and of the scale pans is not carried by the knife-edges when the balance is not in use. The pans rest on the wooden base of the balance, and the beam is carried by the two supporting screws. When we are about to make a weighing the handle M on the base of the balance is turned over to the right. This causes a rod to rise up the inside of the central

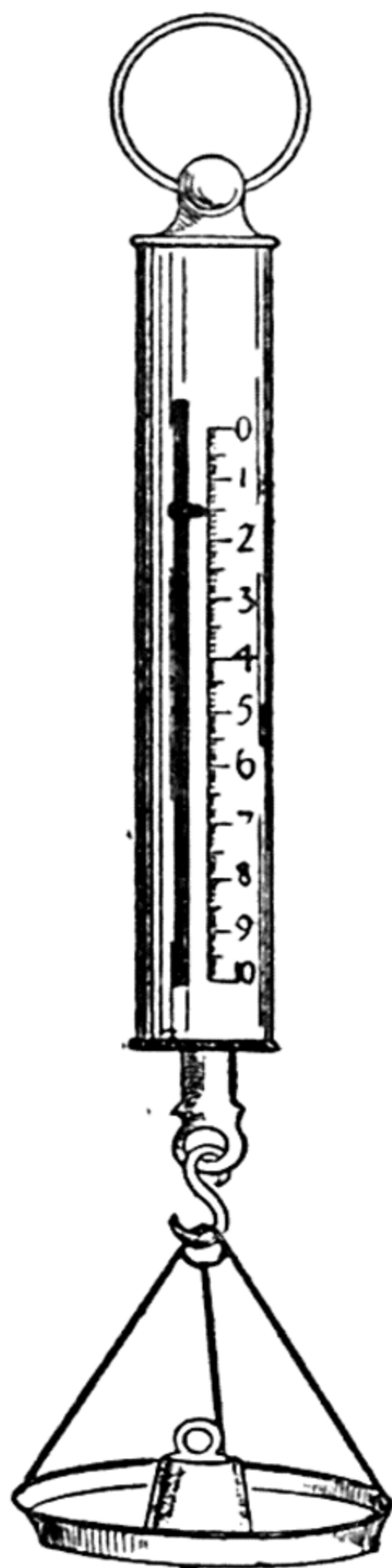


Fig. 28.  
Spring Balance

column, lifting the beam off its supporting screws so that it is then pivoted on its central knife-edge. The

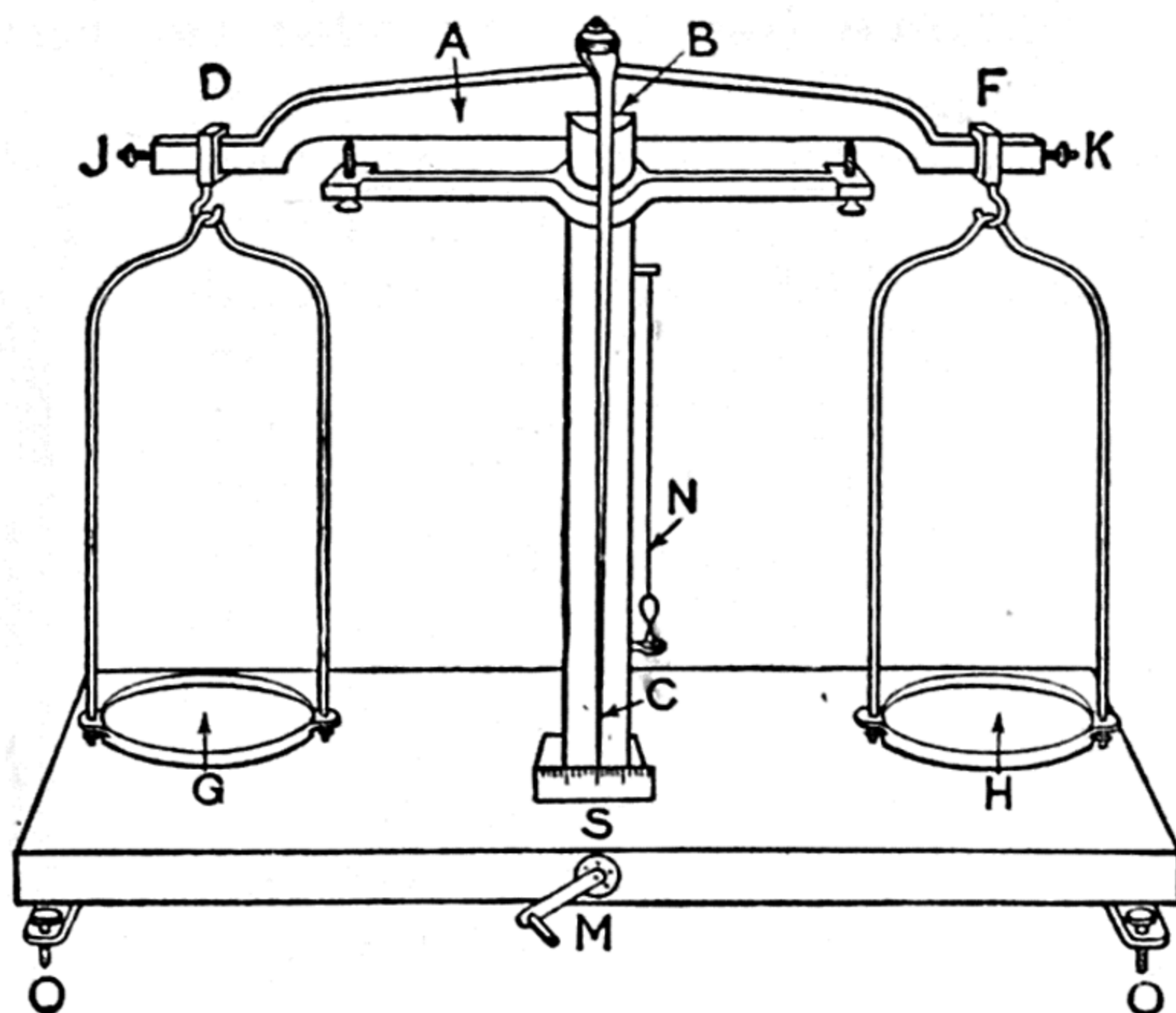


Fig. 29. — The Chemical Balance

stirrups rise with the beam and lift up the pans on the hooks. The balance is kept in a glass case to protect it from damp and air currents.

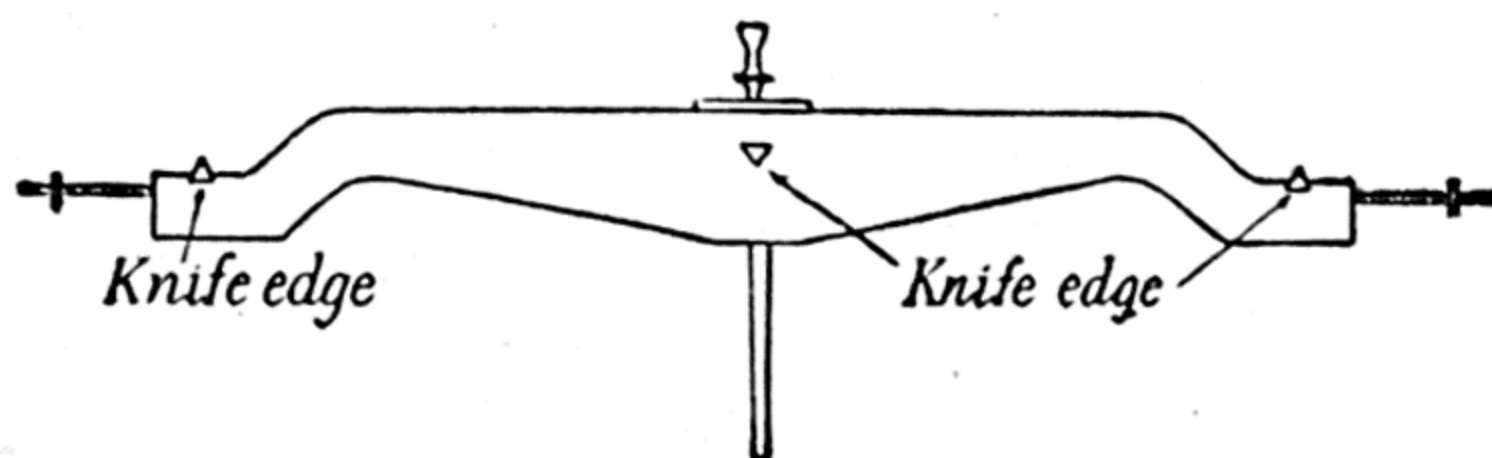
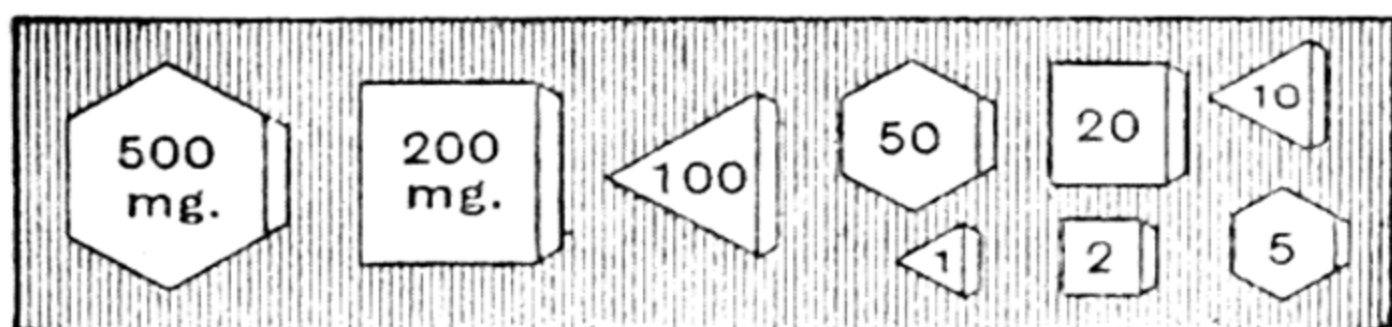


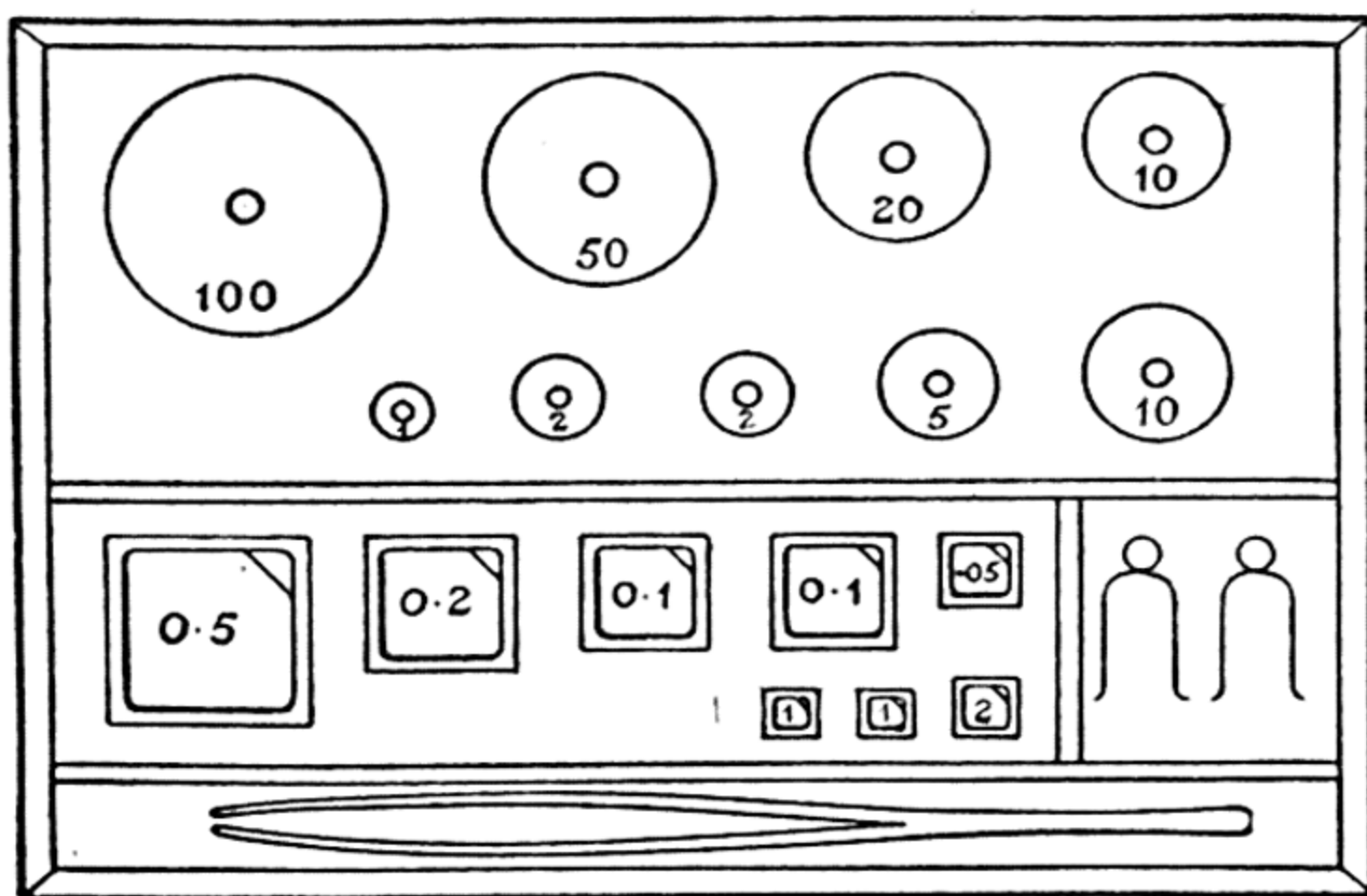
Fig. 30. — Beam of Chemical Balance, showing position of knife-edges

A set of weights for use with such a balance is shown in fig. 31. In many sets the largest weight is 100 grams, and the smallest 10 milligrams (10 milligrams = 0.01 gm.). The weights down to 1 gm. are made of brass

or stainless steel, but the fractions of a gram are usually of nickel silver or aluminium. Notice that usually, as in fig. 31 (*a*), the 500, 50, and 5 milligrams are hexagonal in shape, the 200, 20, and 2 milligrams are square, and the 100, 10, and 1 milligrams are triangular. This enables them to be more easily distinguished. In some



(*a*) Set of milligram weights



(*b*) Set of weights in box

Fig. 31. — Set of Weights

sets the fractional weights are all square, as in fig. 31 (*b*).

To adjust the balance for weighing, the pillar is first made vertical by moving the levelling screws *O*, until the suspension carrying the bob *N* passes centrally through the small ring attached to the pillar. The beam is then gently raised, whereupon the pointer should move over the scale an equal number of divisions on each side of its centre. If the pointer swings more to one side than the other, the beam can be adjusted,

*after lowering*, by altering the position of the adjusting screws J, K, moving the screw on the heavier side of the beam inwards, or that on the other side outwards.

It is not necessary to adjust the weights in the pan until the pointer is motionless at the centre of the scale. This should not be done, in fact, as the pointer may be motionless owing to slight sticking rather than to an exact counterpoise. The weights should be adjusted until the pointer swings equal distances on each side of the centre of the scale when the beam is gently raised.

The following rules should always be observed in weighing: —

1. Chemicals must not be allowed to touch the scale pans, or the latter will be corroded. Chemicals must always be weighed out in glass or porcelain vessels. Care must be taken to see that no water gets on to the pans.
2. Objects must not be weighed while they are hot. They may be weighed as soon as they feel cool to the hand.
3. Place the object to be weighed in the *left-hand* pan.
4. Check your box of weights. See that every weight is present and in its correct place in the box.
5. Weights must always be handled with the forceps provided, and must not be picked up with the fingers.
6. Always lower the beam of the balance before adding or removing anything from either pan.
7. After weighing replace the weights and forceps in the box in their correct positions and close the glass front of the balance case.

In order that no mistake may be made in reading the weights on the scale pan, these should be checked (1) by

noting the weights that have been removed from the box, and (2) by noting the weights as they are returned to the box. Until some facility has been gained in weighing it will be an advantage to note down on paper each weight present on the pan, and to add these up on the paper. Thus:—

Weights on pan	..	50 gm.	
		10 gm.	
		5 gm.	
			500 mg.
			200 mg.
			20 mg.
			10 mg.
Total	..	65 gm.	730 mg.
		65.73 gm.	

### QUESTIONS

- ✓ 1. How would you find (a) the volume of liquid that would fill a medicine bottle, (b) the volume of a brick?
- ✓ 2. How would you find (a) the length, (b) the diameter, and (c) the volume, of a length of wire?
- ✓ 3. Describe how you would find the weight of 25 c.c. of water.

## CHAPTER IV

### INTRODUCTORY HEAT

We all have a clear idea of what we mean by "hotness" and "coldness", although, like other sensations such as colour and sound, it is very difficult, indeed impossible, to express them in words so that they can be understood by anyone who has never experienced them.

[When we heat a beaker of water over a bunsen flame, the water becomes hotter. We explain this by assuming that something, which we call heat, has passed from the hot body to the cold one. Heat is not the same thing as hotness. We shall see this more clearly if we think of two beakers of hot water, a large beaker and a small one. If the water in each is equally hot, the larger beaker of water must contain more heat than the smaller one, although their hotness is the same, because a large beaker of cold water takes longer to heat up over a flame than a small one. We have to put more heat into the larger one in order to heat it up to the same degree of hotness as the smaller one.]

We may compare putting heat into a body to putting water into a tank. As water is put into a tank the level of the water in the tank rises. As we put heat into a body the hotness of the body increases. We may think of hotness as "heat level". When we put equal amounts of water into two tanks, one large and one small, the level of the water is lower in the former than it is in the latter. In the same way, when we heat a large

quantity and a small quantity of water over a flame for the same length of time, the hotness or heat level of the large quantity is lower than that of the small quantity. We can carry the analogy a stage further. Supposing we were to join the large tank of water and the small one by a pipe, water would pass from the smaller tank, where it was at the higher level, to the larger one, where it was at the lower level, until the level was the same in each tank. The direction in which the water flows when the tanks are connected depends on the levels of the water and not on the amount of water in the tanks. In the same way heat passes from a hotter body, where the heat level is higher, to a colder body, where the heat level is lower, although the colder body may actually contain more heat, and it goes on passing until the hotness of the two bodies is the same. [The term **temperature** is used to describe the hotness or heat level of a body.]

[We are able to judge the hotness or coldness of a body by our sense of touch, but this is not always as reliable as we may imagine. Our senses are easily deceived. If we take three basins of water, one cold, one lukewarm, and one as hot as we can bear, and put one hand in the hot bowl and one in the cold for a little while and then put both together in the lukewarm water, the latter will feel cool to the hand that was previously in the hot water and warm to the other. We shall mention later other examples of the way in which our senses deceive us about the temperature or hotness of bodies.]

Obviously we need some more accurate and reliable method of measuring the temperature of a body. This is done by instruments called **thermometers**, which depend on the fact that when heat is put into a body the body expands.

**EXPERIMENT 1. — To show that solids expand when they are heated.**

(a) Arrange a retort-stand horizontally as shown (fig. 32). Place a heavy weight behind the base of the stand so that

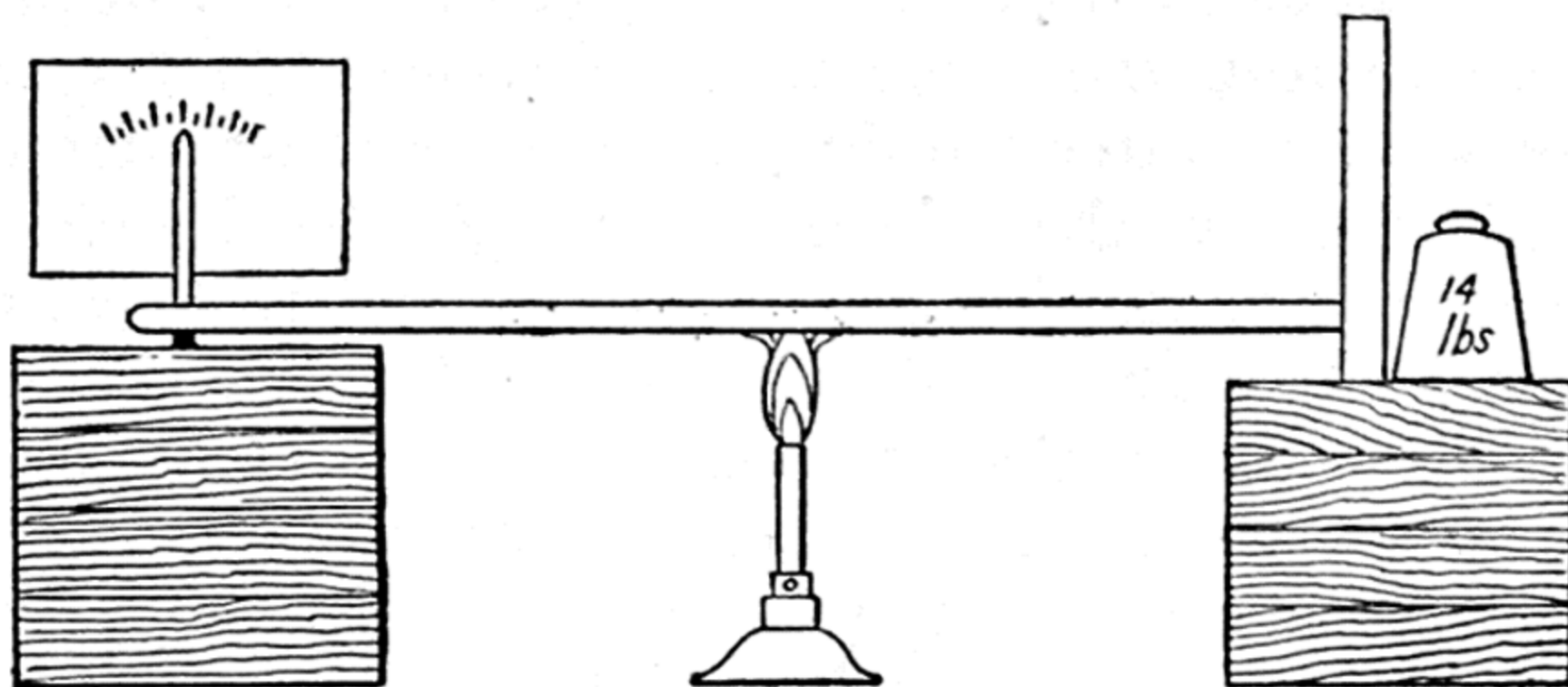


Fig. 32. — To show that a solid expands on heating

expansion will take place in the direction of the other end, which rests on a knitting-needle, to which is attached a light pointer placed in front of a paper scale. If the bar is heated with a bunsen, the pillar of the retort-stand expands and rolls

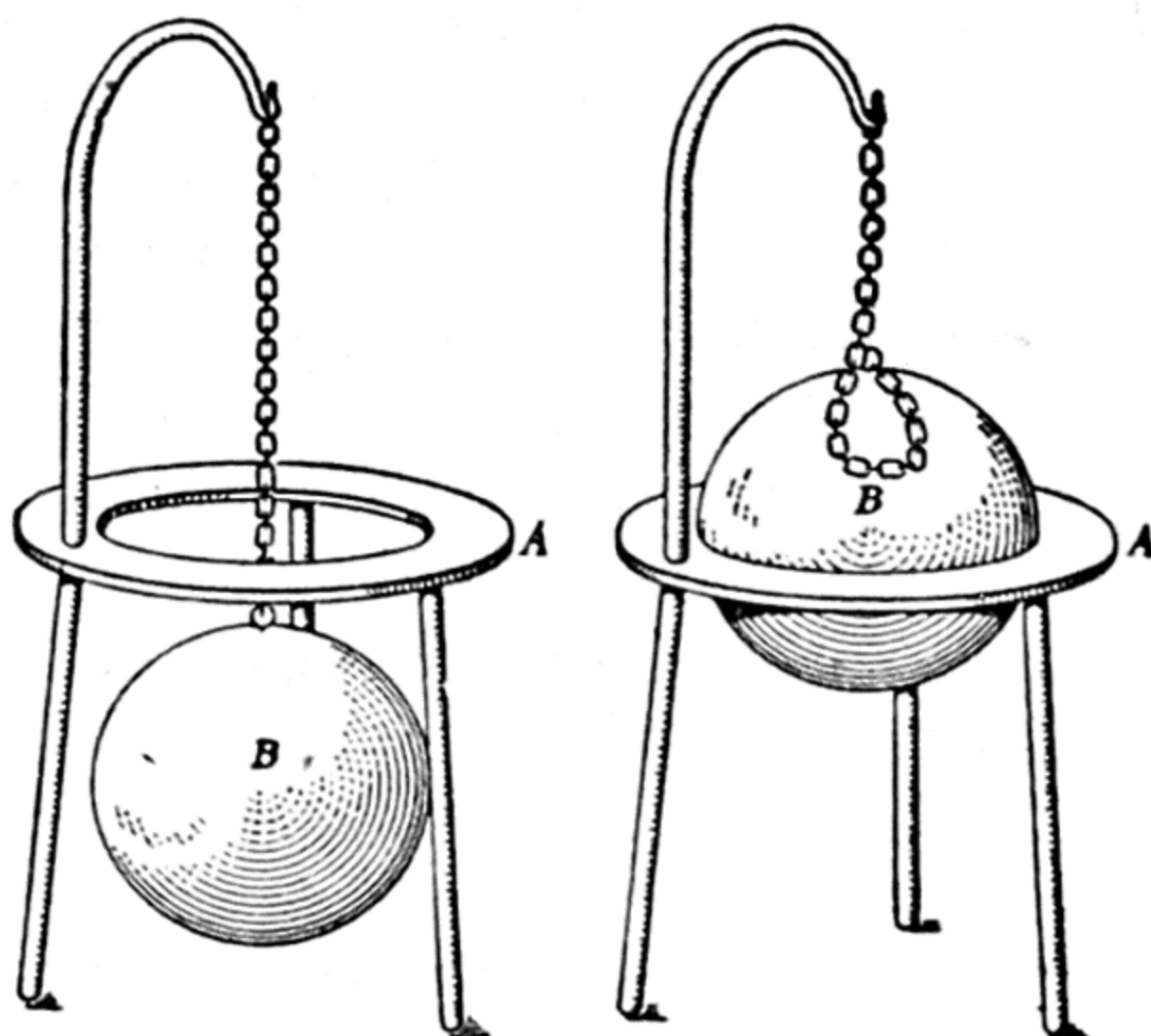


Fig. 33. — Gravesande's Ball and Ring Experiment

over the knitting-needle, causing the needle to rotate, carrying with it the pointer. The increase in length of the retort-stand is much too small to measure with a metre rule, but the above arrangement magnifies the change in length and enables it to be easily seen.

(b) Gravesande's Ball and Ring Experiment. The apparatus consists of a stand carrying a brass ball and a metal ring (fig. 33). The brass ball will just pass through the ring when both are cold. On heating the ball in a bunsen flame for a few seconds it will no longer pass through the ring, although it will do so again on cooling down.

**EXPERIMENT 2. — To show that different metals expand by different amounts when they are heated.** A bimetallic strip (fig. 34), consisting of strips of iron and brass welded together, is heated in a bunsen flame. The strip becomes curved, with the brass on the outside of the curve, but straightens again when it cools. Brass expands more than iron, and by forming the outside of the curve is able to remain in contact with the iron.

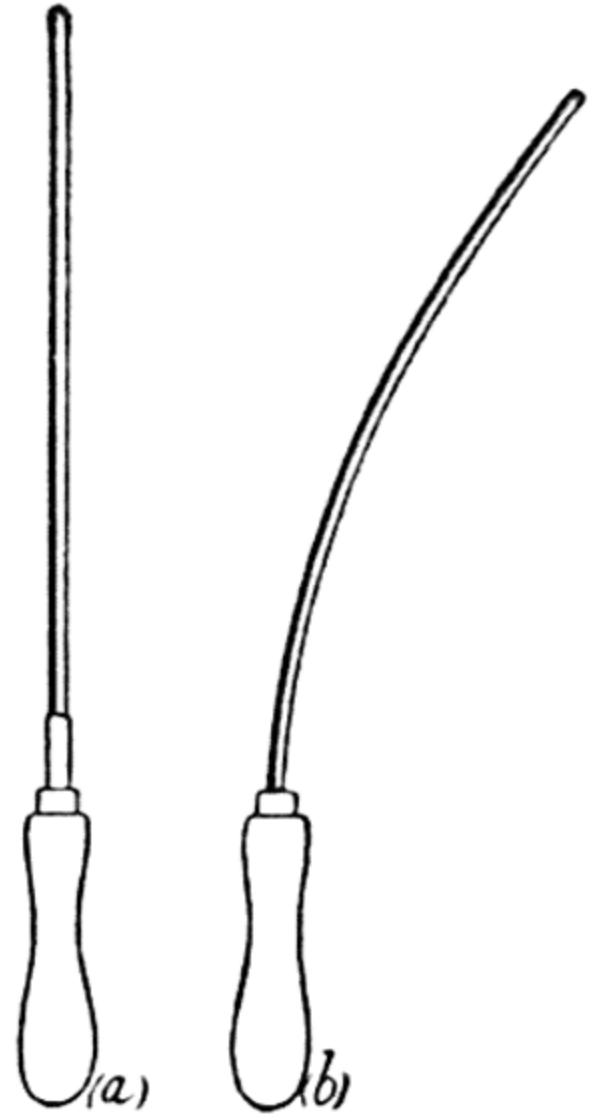
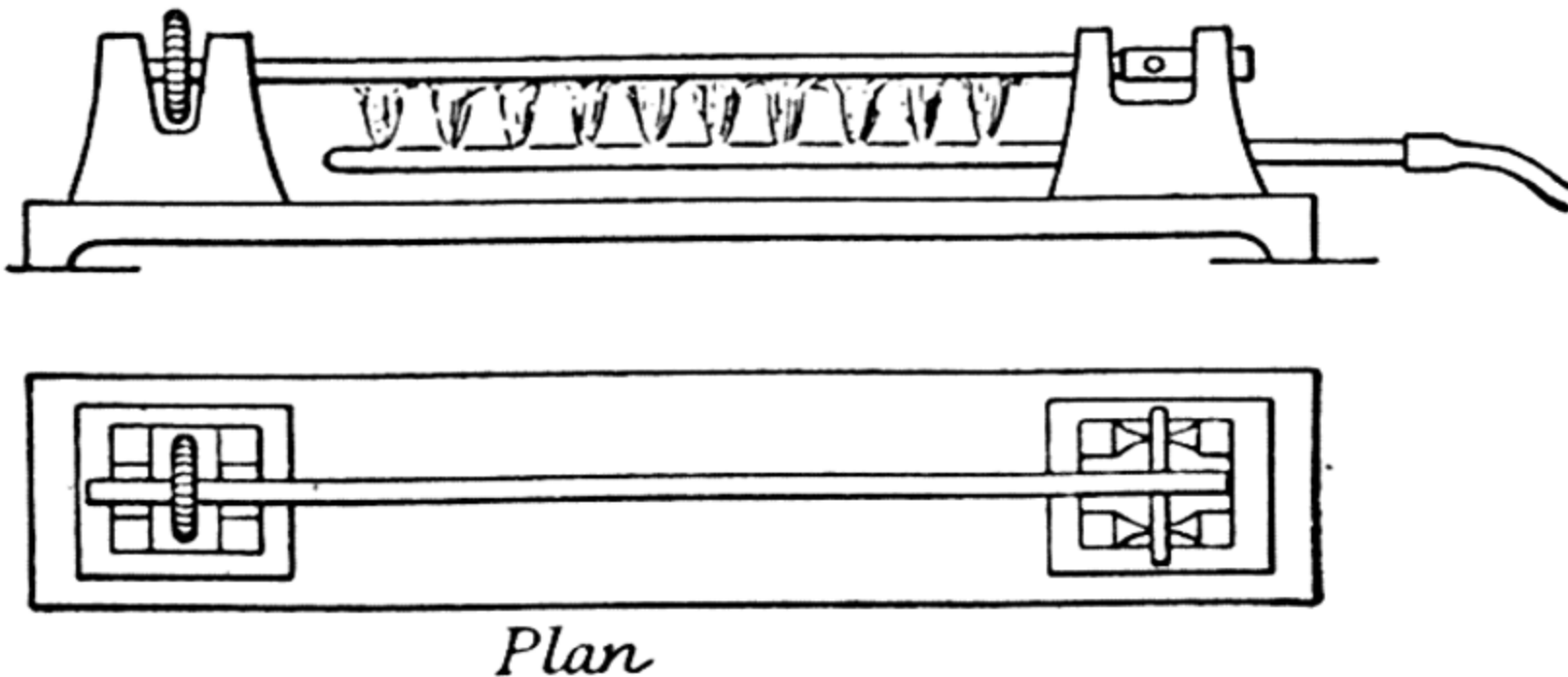


Fig. 34. — Bimetallic Strip  
(a) Before, (b) After heating

**EXPERIMENT 3. — To show that very powerful forces are brought into play when solids expand or contract.** A metal bar is placed in a frame and heated by means of a row of burners underneath it (fig. 35). When the bar is hot an iron bolt is passed through the hole in one end of the bar and the screw



Plan  
Fig. 35. — Expansion of Solids

at the other end is tightened so that the bolt is pressed against two V-shaped jaws. The bar is allowed to cool, and the force of contraction of the bar is sufficient to snap the iron bolt.

The apparatus can also be used to break the bolt as the bar is heated, but in this case the screw is adjusted when the bar is cold, so that the bolt presses against the other two V-shaped jaws.

**EXPERIMENT 4. — To show that liquids expand on heating (fig. 36).**

(a) Fill a flask with water and fit a cork carrying a narrow tube so that the liquid stands at a convenient height in the stem. Warm the flask gently, and notice that for a second or two the level of the liquid falls, but then begins to rise steadily. The momentary fall is due to the fact that the heat gets to the glass vessel before it gets to the liquid inside. The glass vessel, therefore, starts to expand before the liquid inside it does, but once the heat gets to the latter its expansion is so much greater than that of the glass that, although the glass goes on expanding, the liquid rises in the stem. The actual expansion of the liquid is greater than that which we observe, as a part of the expansion of the liquid is concealed by the expansion of the vessel. We observe only the **apparent expansion**.

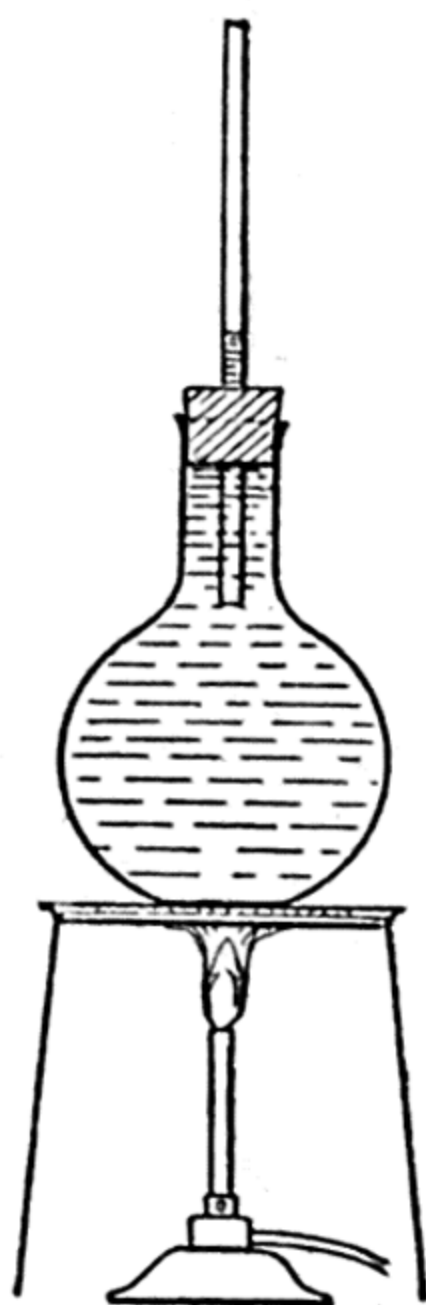


Fig. 36. — Apparatus to show that a liquid expands on heating.

(b) Two or more bulbs of the same size, joined to stems of the same diameter, are filled with different liquids (water, alcohol, mercury, aniline, etc.) so that the liquids stand at the same level in each stem. This level having been marked on each, the bulbs are then immersed in a trough of hot water (fig. 37). When each liquid has reached the temperature of the water in the trough it ceases to rise in the stem. The liquids expand by different amounts although they are heated to the same temperature, and so the level is different in each stem. Which liquid expands the most?

**EXPERIMENT 5. — To show that gases expand on heating.** A flask is fitted with a well-fitting cork and a straight tube, as shown in fig. 38, and the tube is held so that its end is just under the surface of water in a beaker. On heating the flask, or even on placing one's hands round the flask, the air inside is warmed and expands, some of it escaping as bubbles from the end of the tube. On allowing the air in the flask to cool, it

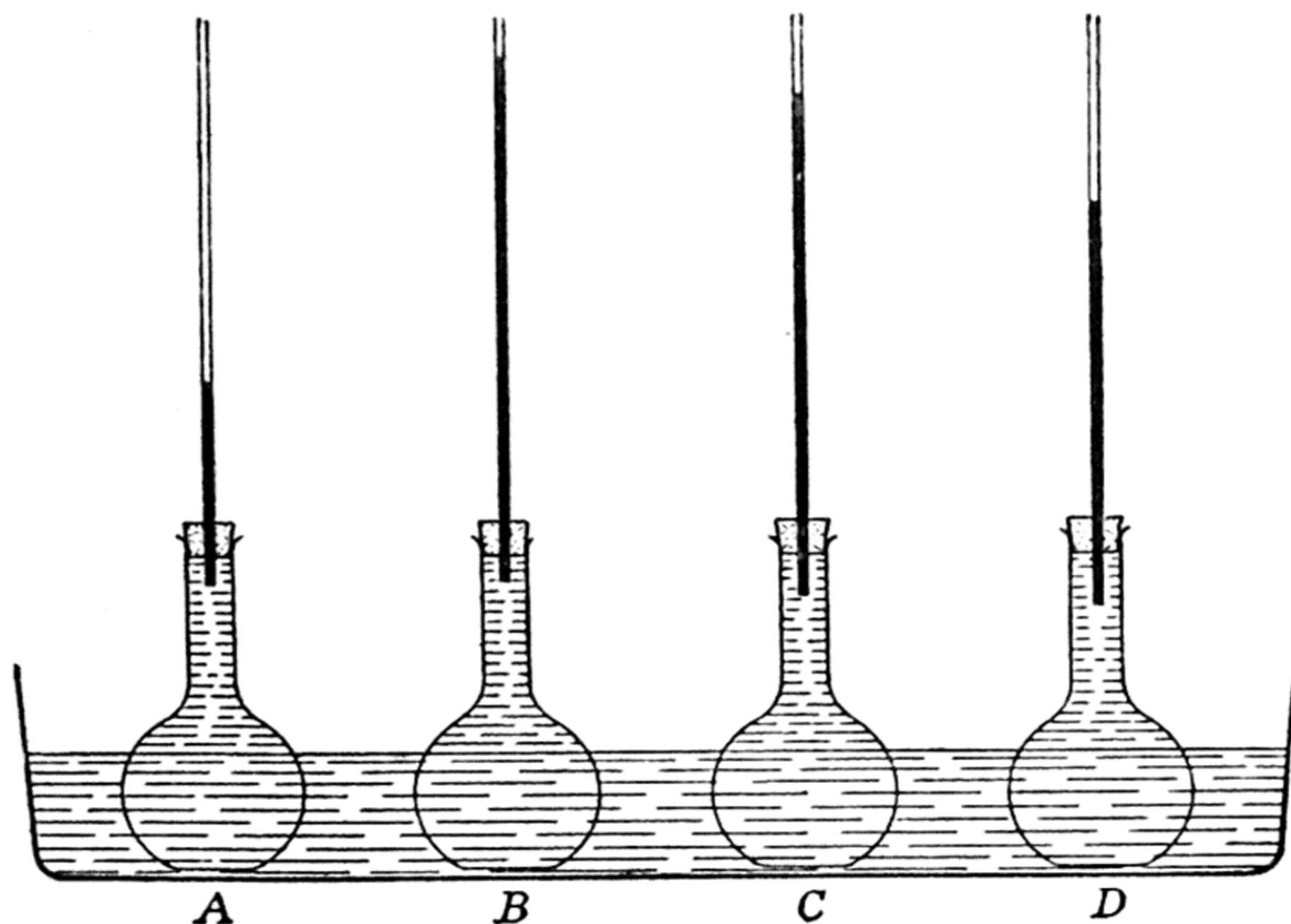


Fig. 37. — To show that different liquids expand by different amounts when heated through the same range of temperature

contracts and water starts to rise up the tube to take the place of the air that has escaped.]

[Gases expand much more than liquids, and liquids much more than solids, for a given increase in temperature. By using a more complicated apparatus than that

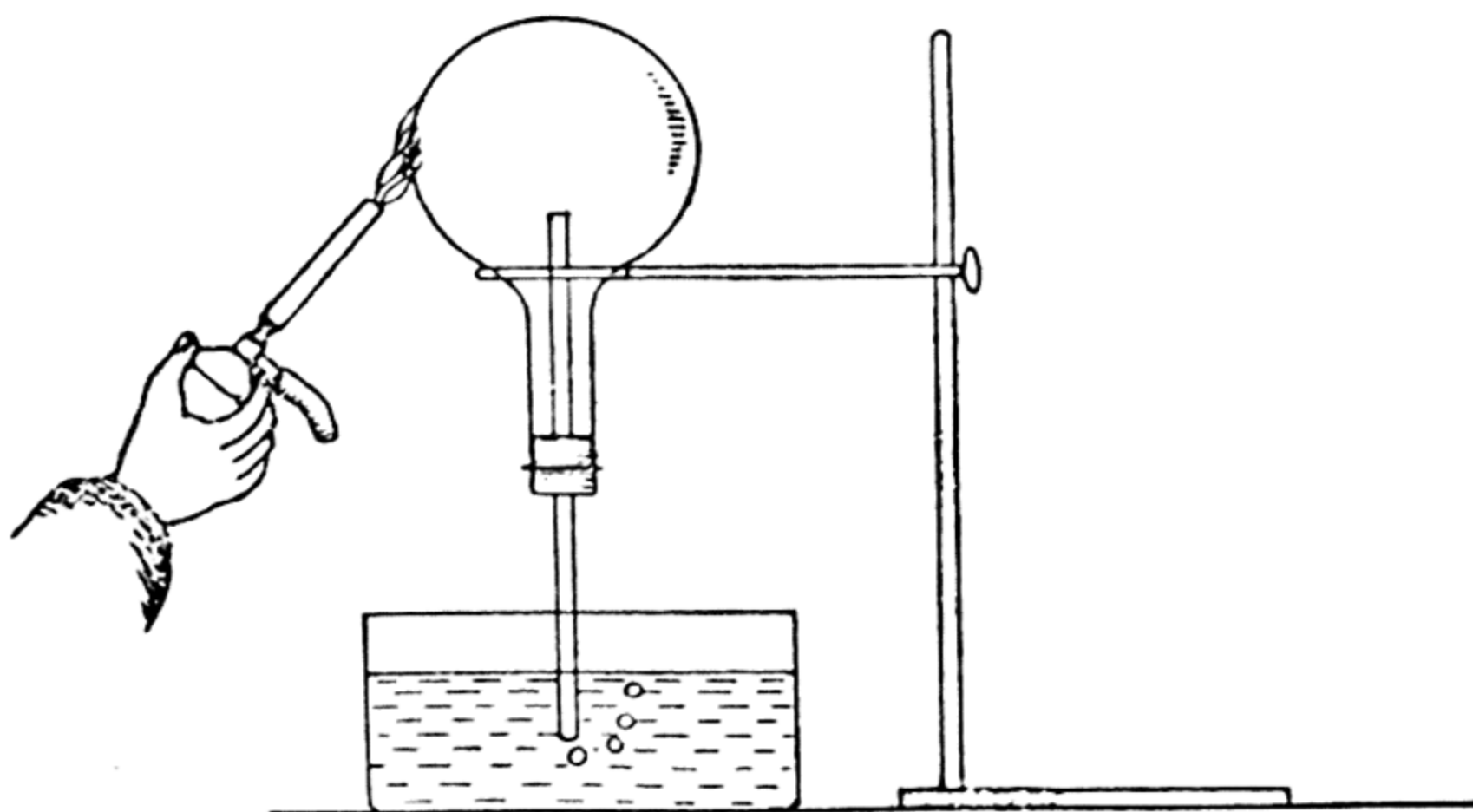


Fig. 38. — To show that a gas expands on heating  
(F 826)

of the preceding experiment, it can be shown that all gases expand by the same amount for the same change in temperature, differing in this respect from both solids and liquids.]

### Other Effects of Heat.

Heat produces many other effects in bodies besides expansion. If we heat a piece of iron sufficiently it will eventually become first red-hot and then, at a higher temperature, white-hot. Bodies that give out red or white light are said to be **incandescent**. The incandescent gas mantle consists of a white earth called thoria, which becomes white-hot in a gas flame, and so gives out light, just as the filament of an electric lamp does when it is heated by passing electricity through it.

When we put heat into a lump of ice, the ice melts, changing from ice, a solid, to water, a liquid, and if we continue to heat the water, it will eventually boil and the liquid water will be converted into a gas or vapour called steam. We are able to change many other bodies from solid to liquid and from liquid to gas by heating them to a sufficiently high temperature. Thus molten iron can be caused to boil, although a very high temperature is required for this. Substances that do not liquefy, even when very strongly heated, are said to be **refractory**, and some of them, such as certain kinds of clay and brick, are used for lining furnaces.

### [Solids, Liquids, and Gases.

[Matter can exist in three **states**, solid, liquid, and gaseous, and to convert a solid into a liquid or a liquid into a gas we must supply heat. Solids are substances that have a definite shape, which they keep unless subjected to considerable force. Liquids have no shape of their own but take the shape of any vessel into which they are placed. Gases also take the shape of any vessel into which they are placed, but differ from liquids in

that they have no definite volume, and will expand to fill any vessel, however large.] Liquids that flow easily are **mobile**, but those, like treacle and tar, that flow very slowly are said to be **viscous**. A viscous liquid will flow more easily when it is warm. It is not always easy to say whether a given substance is a solid or not, for there are substances, such as pitch, which seem fairly obviously solids but which on standing for some time gradually spread out over a flat surface and move down a slope, very slowly indeed. [We may therefore think of such substances as very viscous liquids.]

[Gases can be caused to liquefy, and even to solidify, by taking heat from them so that they become colder. Carbon dioxide, the gas that is put into soda-water, is used, after it has been rendered solid by cold, to keep ice-cream from melting. Solid carbon dioxide is sometimes called "dry ice", as when it is warmed it does not liquefy but changes direct into a gas.]

[EXPERIMENT 6.—To solidify mercury by means of "dry ice". Put a little "dry ice" in a small dish, add a little ether or alcohol, and then about 1 c.c. of mercury. In a few seconds the mercury is frozen solid and can be taken out with a pair of tongs and shown to be no longer liquid. As it warms up again it liquefies. The purpose of the ether or alcohol in this experiment is to ensure a better contact between the mercury and the solid carbon dioxide.]

[Another effect of heat is to bring about chemical reaction. Burning is a very common example of this. Many substances, when heated to a sufficiently high temperature in air, catch fire and are converted into a vapour, leaving perhaps a little ash. Such a change is quite different from the boiling of water, for although in both cases vapours have been formed, we can get the water back again by cooling the steam, whereupon it condenses. But we cannot restore a piece of paper or candle by cooling down the vapours produced when they burn.] Changes that are reversible when the

conditions are reversed, like the melting of ice or metal or the boiling of water, are said to be **physical** changes, while changes like the burning of paper and other combustible bodies, that are not reversible, are said to be **chemical** changes.

[All living things, both plant and animal, are killed by too high a temperature. They will burn if they are heated sufficiently, but a much lower temperature is enough to kill them. Boiling water is often used to kill a nest of ants, and if some of the water falls on grass it will be obvious in a day or two that the grass has been killed also. When we touch a hot iron or drop boiling water on our skin, a blister forms where the skin has been killed and remains until new skin has grown underneath.]

### ✓ Some Effects and Applications of Thermal Expansion.

When a metal expands or contracts, such large forces are brought into play that it is necessary in engineering to allow for this expansion or contraction rather than try to prevent it. Rails on a railway are bolted together in such a way that there is a small gap between adjacent rails to allow for the increase in length that occurs when the rails are exposed to the summer sun. The bolts, also, are fitted in oval-shaped slots so that they too can move their position a little as the length of the rail changes. Although one sometimes sees it stated in the little paragraphs of the popular journals that, for example, "the railway line from London to Edinburgh is 300 yards longer in summer than in winter", it must not be imagined that the two stations are any farther apart. The whole of this expansion is taken up by the ends of consecutive rails closing up the gaps between them. The ends of metal bridges are mounted on rollers, over which the girders can slide, as much as two feet being allowed in the case of a very long bridge.

Pipes to carry steam are bent at intervals into loops or coils, the curved part of the piping taking up the increase in length of the tube by altering slightly in shape.

The time-keeping of a clock is regulated by its pendulum, which swings more slowly when it increases in length. In summer, therefore, a clock goes slow. In the more expensive clocks the change in length of the pendulum is compensated for. One method of compensation is to use a "grid-iron" pendulum (fig. 39). This consists of a number of rods joined together so that the rods shown dark in the figure expand downwards, while those shown light expand upwards. The total length of

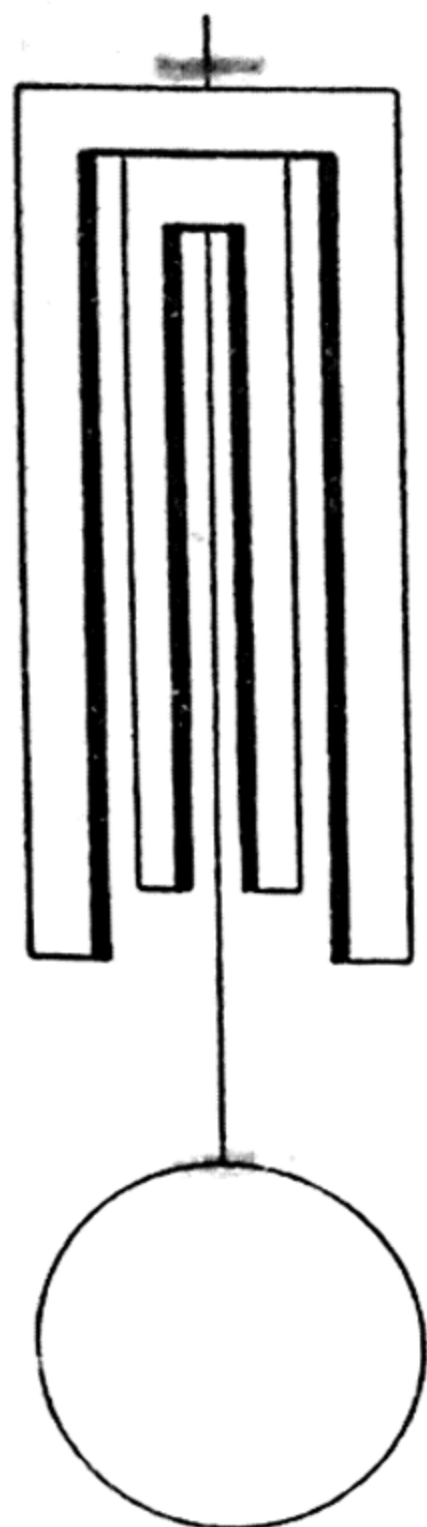


Fig. 39. — Grid-iron Pendulum

the dark rods is greater than that of the light ones, but by making the former of iron, which expands less than the brass used for the others, we can so arrange it that the length of the pendulum from

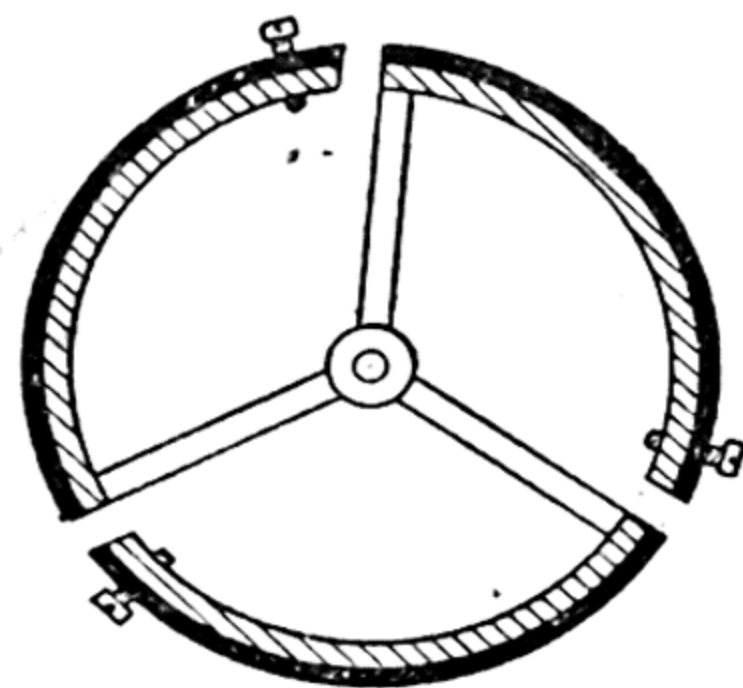


Fig. 40. — Balance Wheel of Chronometer

the pivot to the bob does not change when the temperature alters. Another method is to use a pendulum rod made of an alloy called **invar** (see p. 48).

A watch has no pendulum, but its time-keeping is controlled by the oscillations of a balance-wheel, which alternately compresses the hair-spring and allows it to uncoil again. When the temperature rises the spokes of the wheel increase in length and as a result the balance-wheel vibrates more slowly. This is compensated for by having the rim of the wheel made of two

different metals bolted together, with the less expansible metal on the inside, so that as the spokes increase in length outwards the rim curves inwards. In this way the average distance of the rim from the centre of rotation does not alter with change in temperature. ]

In the manufacture of electric lamps and many kinds of scientific apparatus it is necessary to seal a wire into glass. This can be done by heating the glass until it softens, and then pushing the wire through it. If the wire does not contract the same amount as the glass when it cools the seal will break. [Platinum expands and contracts by the same amount as glass but is much too expensive for electric lamps, for which an alloy of iron and nickel called **platinite** is used. Platinite consists of steel alloyed with 42 per cent of nickel and sticks better to glass when sheathed with a thin layer of copper. ]

[The measuring tapes used by surveyors are made of invar. Invar contains 36 per cent of nickel and 64 per cent of steel and has a negligible thermal expansion. ]

Concrete, although it is very tough and hard, is not sufficiently strong for purposes where pulling or bending strains are involved. Its mechanical strength can be greatly increased by reinforcing it with iron rods or plates (reinforced concrete). It is only possible to embed this reinforcing in concrete because the thermal expansions of iron and of concrete are almost exactly the same.

Although thermal expansion is so often a complication, it has certain uses. Steel plates are riveted together with hot rivets, which, when they cool, contract and hold the plates very tightly together. Similarly, the metal rim of a wheel can be fitted by heating the rim until it is just large enough to be slipped over the cold wheel. On cooling, the rim contracts and grips the wheel very tightly.

## The Measurement of Temperature.

The commonest form of thermometer consists of a glass stem made of thick-walled capillary tubing (capillary tubing has a fine bore, i.e. a small internal diameter) to which is attached a thin-walled bulb full of mercury. When this is placed in a warm liquid heat easily passes through the thin walls of the bulb to the mercury inside, which expands so that a thin column, or thread, of mercury rises up the stem. The hotter the liquid the farther the mercury thread rises. Thermometers are made by skilled workmen called glass-blowers. A suitable length of capillary tubing with a uniform bore is selected, and the thin-walled bulb, which is made separately, is then joined on to the stem by heating the ends of the glass until they become soft, pressing them together, and then heating the joint until the two pieces of glass fuse together. The next step is to fill the bulb with mercury. The mercury cannot be poured down the capillary tube, because the bulb is full of air and there is not room in the fine bore of the stem for this air to escape and for mercury to pass down the tube at the same time. In order to get the mercury in, the air in the bulb is heated so that it expands and some of it comes out of the stem, the end of which is then placed under mercury in a dish. As the bulb cools the air left inside contracts and a little mercury rises up the

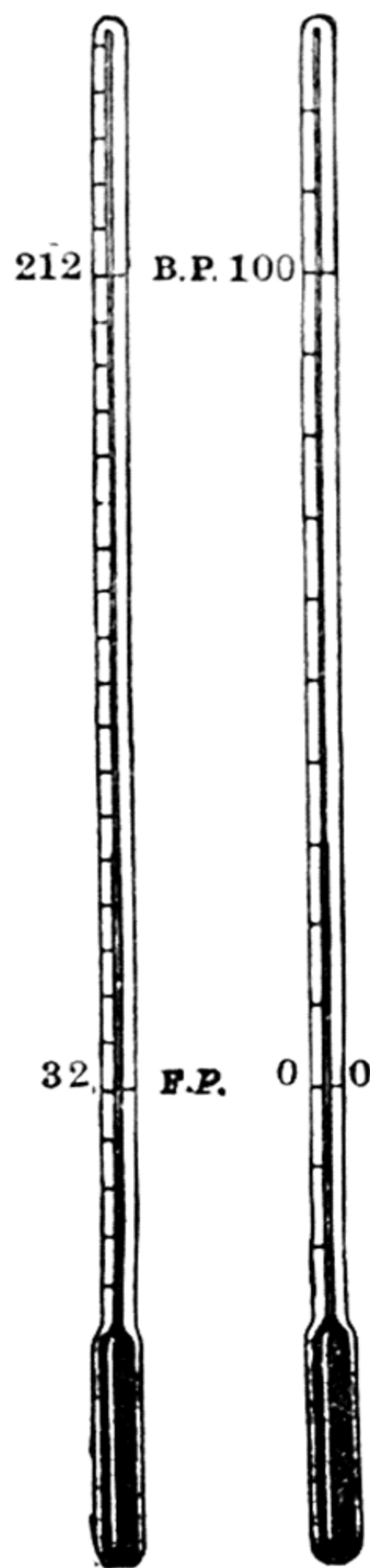


Fig. 41. — Fahrenheit and Centigrade thermometers.

stem and into the bulb to take the place of the air that has escaped. By repeating this process the bulb can be nearly filled with mercury, which is then heated until it boils. The vapour from the boiling mercury displaces all the rest of the air from the bulb and stem, and the latter is again placed under mercury. As the bulb cools the mercury vapours condense and fresh liquid mercury enters from the dish to take their place, so that we now have bulb and stem completely filled with mercury — too much mercury, in fact. The bulb is heated again, this time to a temperature a little above the highest temperature the thermometer is required to read. The excess mercury escapes from the top of the stem. When no more escapes the top of the stem is sealed by heating it with a very small and very hot blow-pipe flame until the molten glass closes over the fine capillary, so that no air can enter the stem.

The thermometer has now been made, but as yet has no scale of temperature marked on it. In order to obtain a scale, the thermometer is first placed in *melting* snow or ice and the level at which the mercury thread stands is marked on it. This is the **Lower Fixed Point**. The **Upper Fixed Point** is then found by immersing the thermometer in steam from boiling water and again marking the level of the mercury.

**EXPERIMENT 7. — To find the Lower Fixed Point of a Thermometer.** The thermometer is placed in a funnel filled with melting snow (fig. 42), so that when the level of the mercury is quite steady the tip of the mercury column is just visible above the top of the snow. A scratch is then made on the stem level with the top of the mercury column.

**EXPERIMENT 8. — To find the Upper Fixed Point of a Thermometer.** The apparatus used is called a **hypsometer** (fig. 43), and consists of a copper vessel, the lower portion of which contains boiling water. The upper part of the vessel is cylindrical, and has double walls, so that the steam rises up the inner cylinder and comes down the outer before escaping at the outlet. The thermometer is inserted through a cork

at the top so that its bulb is out of reach of splashes of water, because if the latter is impure its temperature will be slightly higher than that of the steam. After the water has been boiling for some minutes and the level of the mercury is quite steady the thermometer is adjusted so that only the tip of the mercury thread is visible above the cork. After waiting another minute

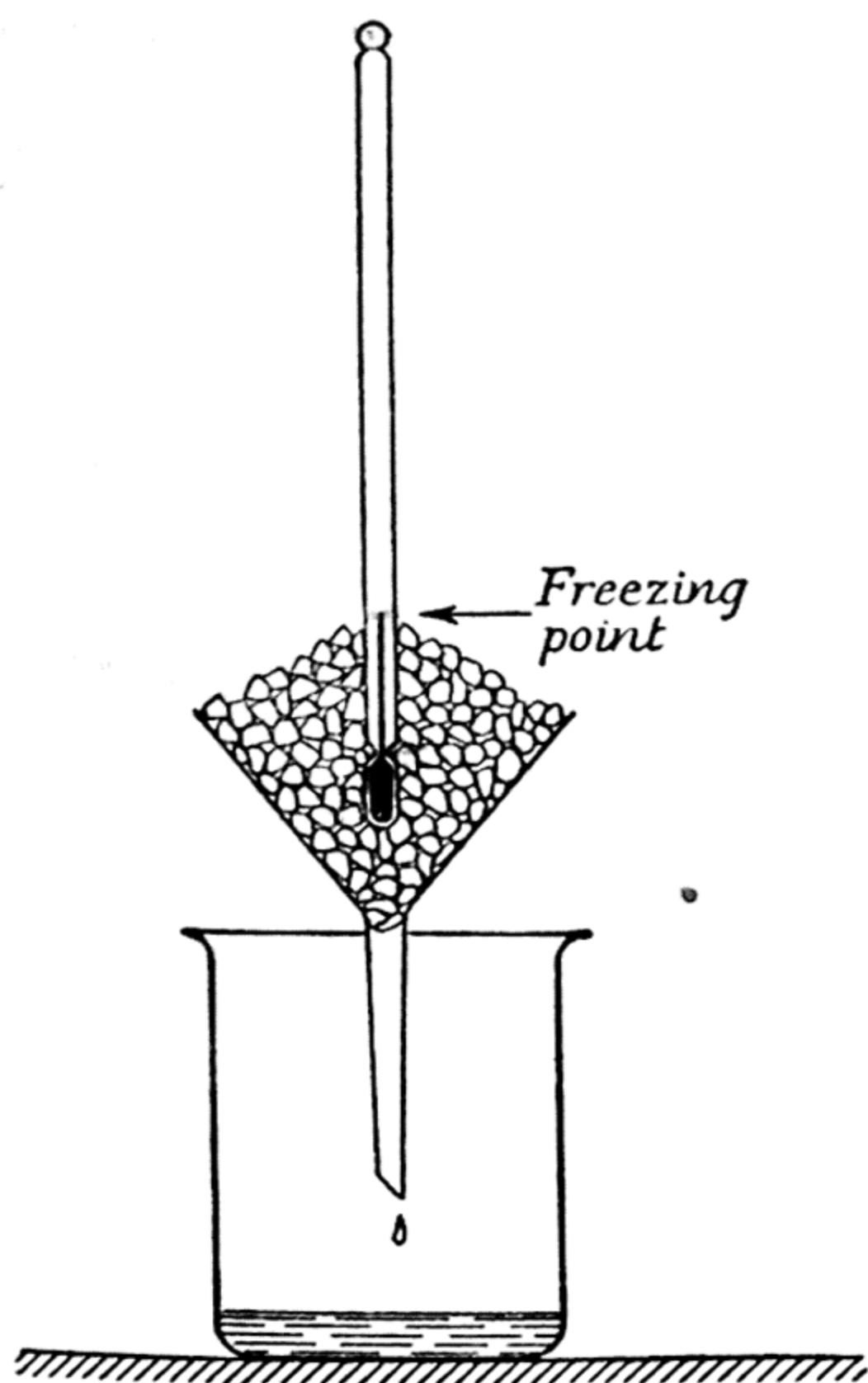


Fig. 42. — To mark the lower fixed point of a thermometer.

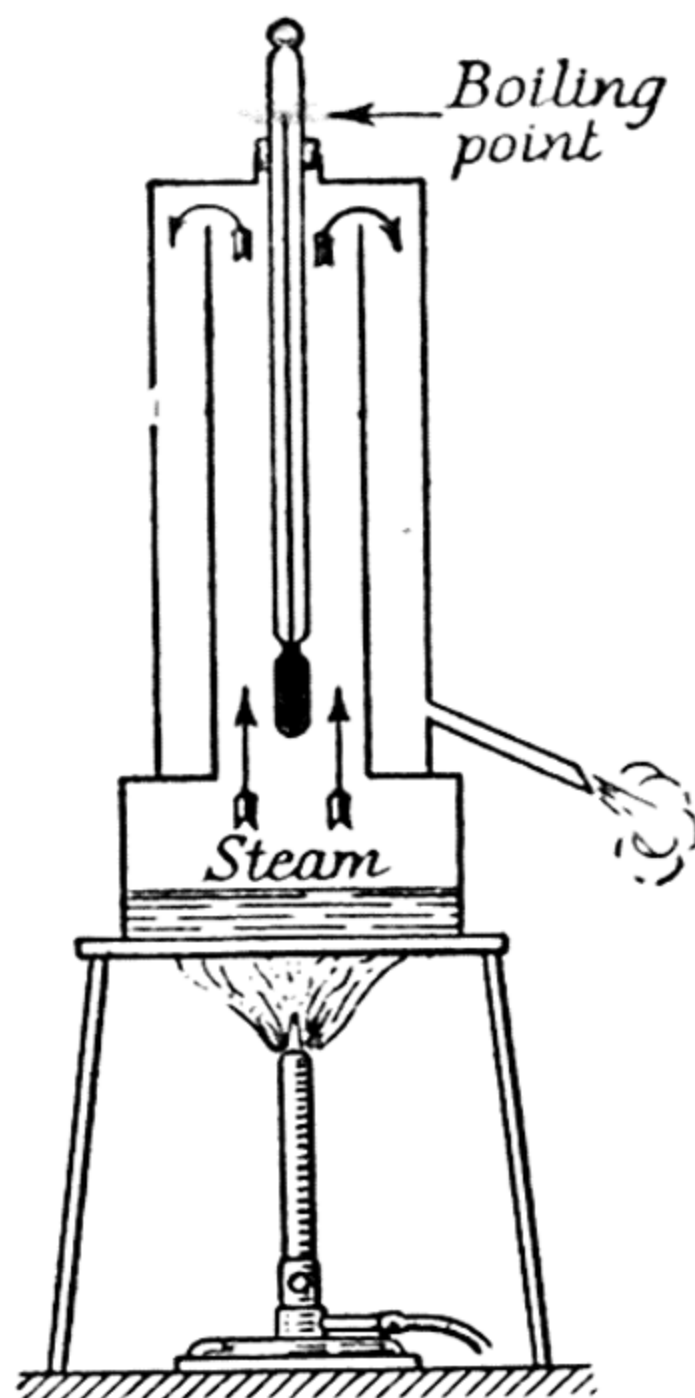


Fig. 43. — To mark the upper fixed point of a thermometer.

or two a scratch is marked on the stem level with the top of the mercury column. The height of the barometer (p. 115) is now read, and if this height is 76 cm. the mark made is the upper fixed point. The boiling-point of water varies somewhat with changes in the atmospheric pressure, and if the height of the barometer is not 76 cm. it will be necessary to make a correction. This can be done from tables, but the details are beyond us at this stage.

Having marked the two Fixed Points, we can then proceed to mark the scale by dividing the length of stem between the two fixed points into a number of equal divisions called **degrees**. The number of subdivisions we mark will depend on the scale of temperature we decide to use. The scale in common use in this country and in America is called the **Fahrenheit** scale, after G. D. Fahrenheit (1686–1736), the first maker of accurate thermometers. On this scale the melting-point of ice is taken as  $32^{\circ}$ , and the boiling-point of water as  $212^{\circ}$ , the interval between the fixed points being divided into 180 equal divisions. The scale used for everyday purposes on the Continent and for scientific work all over the world is called the **Centigrade** scale. On this scale the melting-point of ice is

taken as  $0^{\circ}$  and the boiling-point of water as  $100^{\circ}$ , the interval being divided into 100 equal parts. In each case the scale can be extended above the upper fixed point and below the lower fixed point by marking off intervals of the same size as those between the fixed points.

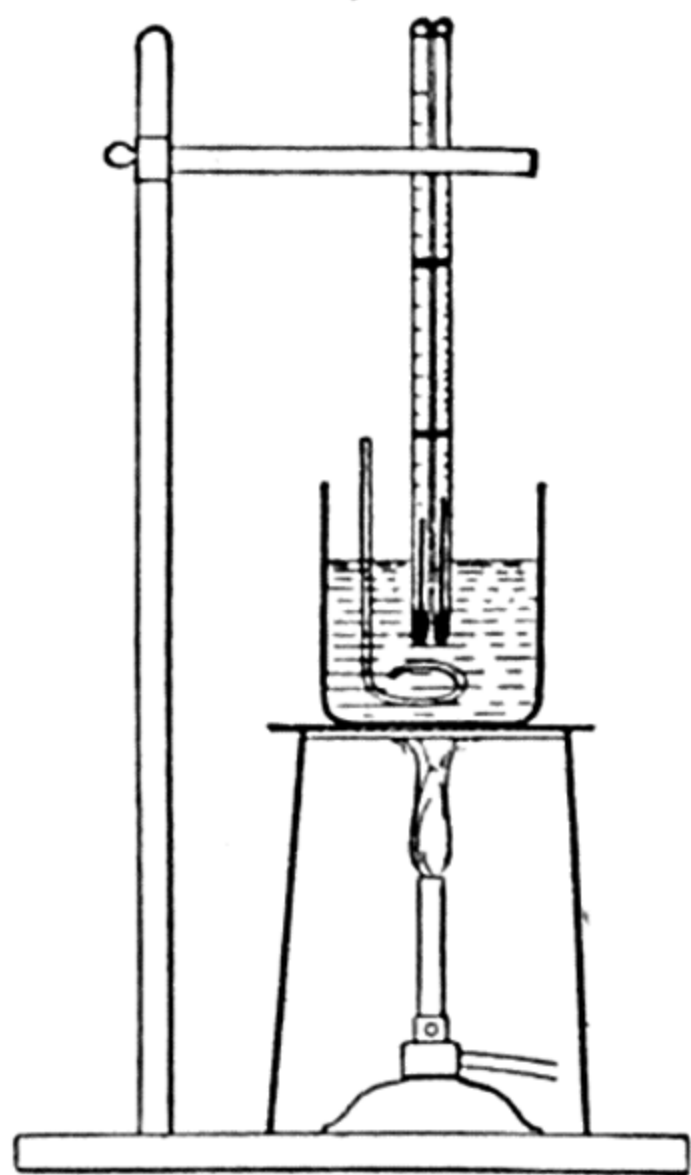


Fig. 44. — Comparison of Fahrenheit and Centigrade scales of temperature.

**EXPERIMENT 9. — To compare the Centigrade and Fahrenheit scales of temperature.** Take a Centigrade and a Fahrenheit thermometer and fix them together with a couple of elastic rubber bands so that the two bulbs are side by side. Suspend the thermometers by thread from a retort stand so that the bulbs are immersed in water in a beaker (fig. 44). Use a piece of stout wire, bent at the bottom in the form of

a circle, as a stirrer, and gradually heat the water in the beaker by a bunsen burner, the stirrer being used to make sure that the water is heated uniformly. Take simultaneous readings of the two thermometers at intervals, removing the bunsen

while you do so. Enter your readings in a table and plot them on a graph as shown in fig. 45. The points will be found to lie very nearly on a straight line.

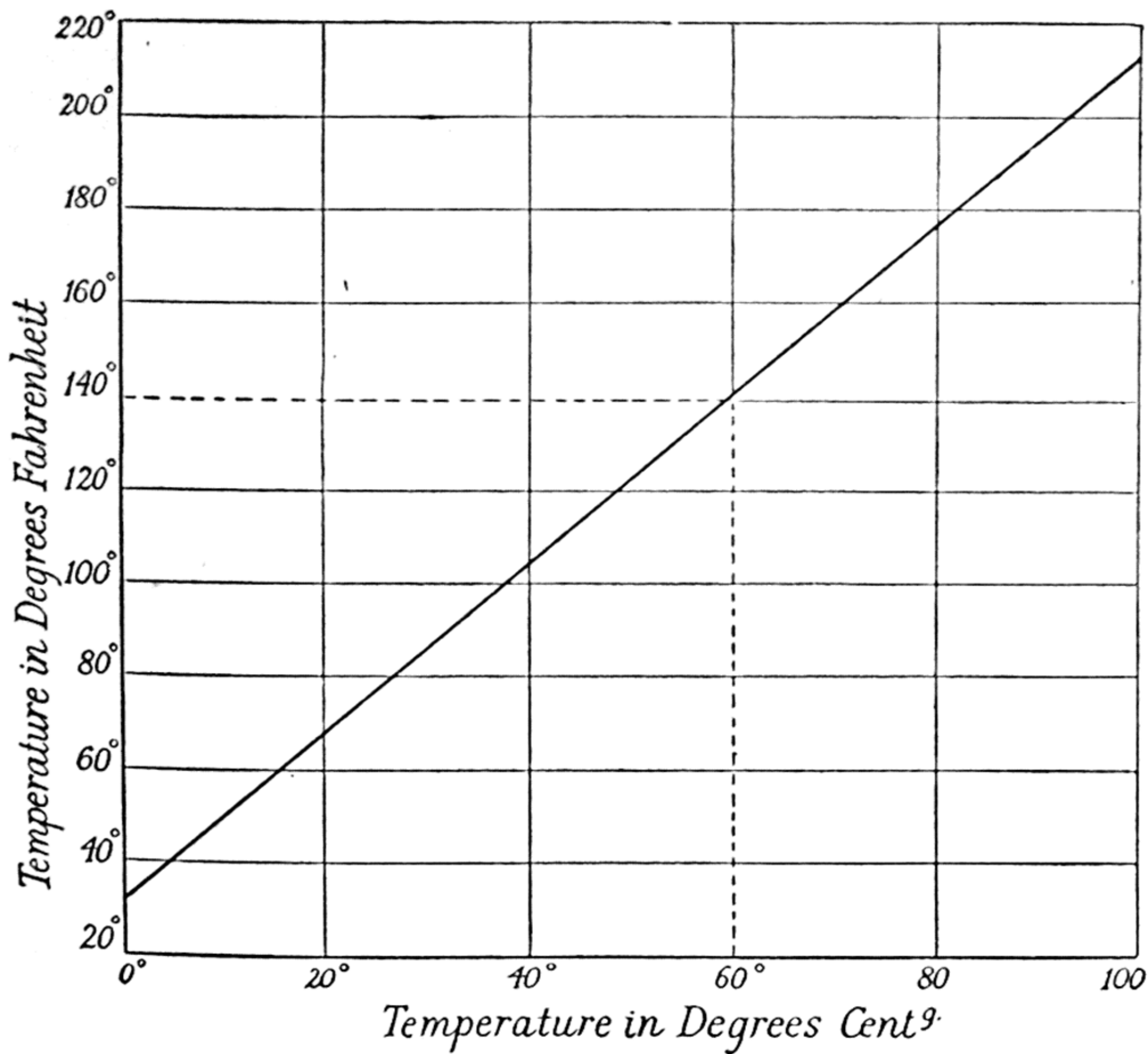


Fig. 45. — Graph showing relationship between Fahrenheit and Centigrade scales of temperature

The graph obtained in the above experiment can be used to find a Centigrade temperature corresponding to a given Fahrenheit one, or vice versa. From the figure it will be seen that  $60^{\circ}$  C. corresponds to  $140^{\circ}$  F. By extending the line at each end we may use it to compare temperatures beyond the range actually observed in the experiment. Since we know that the graph is a straight line we can draw it if we know only

two pairs of corresponding temperatures, and we have seen above that  $0^{\circ}\text{C.}$  corresponds to  $32^{\circ}\text{F.}$  and  $100^{\circ}\text{C.}$  corresponds to  $212^{\circ}\text{F.}$  These are sufficient to enable us to draw the graph.

It is very easy to convert a Centigrade temperature to the corresponding Fahrenheit temperature, and vice versa, by calculation. All we have to remember is that  $0^{\circ}\text{C.}$  corresponds to  $32^{\circ}\text{F.}$  and that 180 Fahrenheit degrees = 100 Centigrade degrees.

**EXAMPLE.** — To find the Fahrenheit temperature corresponding to  $15^{\circ}\text{C.}$

$$\begin{aligned} 15^{\circ}\text{C.} &= 15 \text{ Centigrade degrees above freezing-point} \\ &= 15 \times \frac{180}{100} \text{ Fahrenheit degrees above freezing-point} \\ &= 27 \text{ Fahrenheit degrees above } 32^{\circ}\text{F.} \\ &= 59^{\circ}\text{F.} \end{aligned}$$

**To find the Centigrade temperature corresponding to  $86^{\circ}\text{F.}$**

$$\begin{aligned} 86^{\circ}\text{F.} &= (86 - 32) \text{ Fahrenheit degrees above } 32^{\circ}\text{F.} \\ &= 54 \text{ Fahrenheit degrees above freezing-point} \\ &= 54 \times \frac{100}{180} \text{ Centigrade degrees above } 0^{\circ}\text{C.} \\ &= 30^{\circ}\text{C.} \end{aligned}$$

Mercury is not the only liquid used in thermometers. Sometimes alcohol is used instead, generally with the addition of some colouring matter to render it more easily visible. Alcohol is much cheaper than mercury and also expands nearly ten times as much for the same rise in temperature, but it is not used in laboratory work, because alcohol boils at  $78^{\circ}\text{C.}$ , well below the boiling-point of water, and such a thermometer would be broken if placed in boiling water. Mercury does not boil until its temperature is  $357^{\circ}\text{C.}$  On the other hand, mercury freezes at  $-39^{\circ}\text{C.}$  (i.e. 39 degrees Centigrade *below*  $0^{\circ}\text{C.}$ ), while alcohol remains fluid until  $-110^{\circ}\text{C.}$  Alcohol thermometers are commonly used for weather recording.

## The Clinical Thermometer.

The temperature of the healthy human body remains remarkably constant at about  $98.4^{\circ}$  F., being a little lower in the morning and a little higher at night. During illness, however, the body temperature often changes. In a few illnesses it may be below normal (sub-normal), but more usually it rises, and in extreme fevers it may rise to  $105^{\circ}$  F., or even a little higher. Knowledge of a patient's temperature is an assistance to a doctor or nurse in deciding what treatment to give.

The temperature of the human body is usually taken either under the tongue or in the armpit, where the bulb

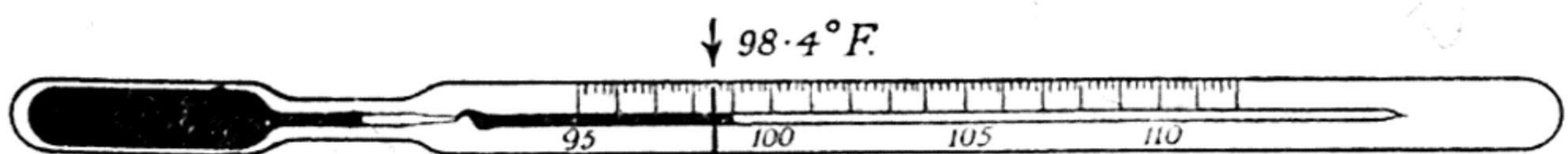


Fig. 46. — Clinical Thermometer. Note the constriction in the stem

of the thermometer is completely surrounded. If an ordinary thermometer were used it would take a long time to reach the correct reading, and as soon as it was taken out the mercury would start to fall before the instrument could be read. The clinical thermometer overcomes these drawbacks. It consists of a small bulb with a scale reading from only  $95^{\circ}$  F. to  $110^{\circ}$  F., subdivided into fifths of a degree (fig. 46). Just above the bulb there is a small constriction in the bore of the stem. As the mercury expands it pushes its way past the constriction, but on cooling the thread breaks off at the constriction, leaving behind the portion in the stem to mark the highest temperature reached. The instrument can be re-set by giving the tube a jerk (which requires a certain knack), whereupon the mercury thread is shaken down past the constriction.

## The Maximum and Minimum Thermometer.

At meteorological stations records are made of the highest and lowest temperatures reached each day. It is obviously impossible to employ a man merely to

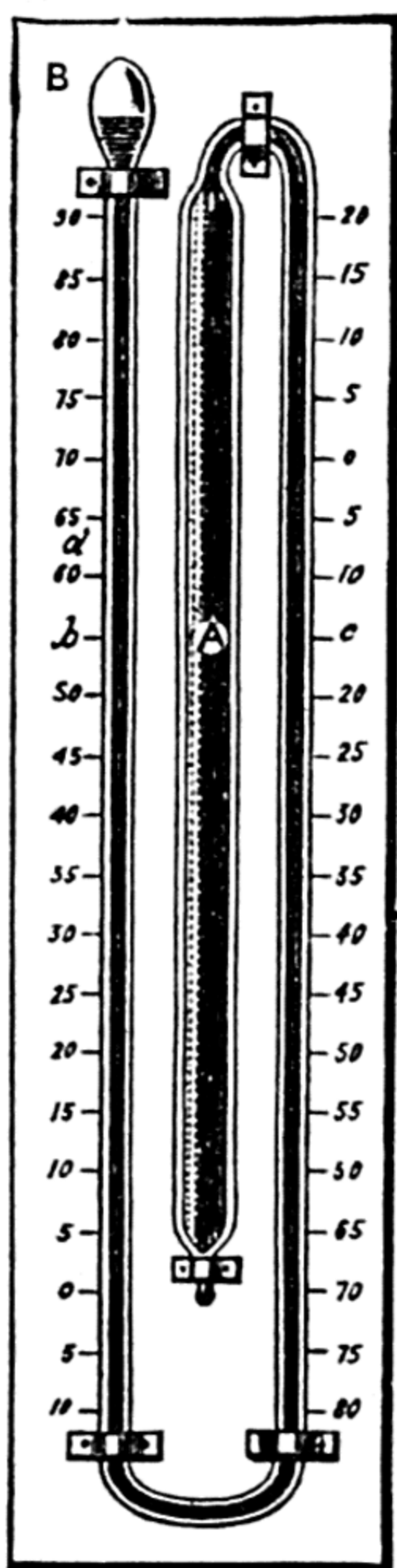


Fig. 47. — Six's Maximum and Minimum Thermometer.

watch the thermometer all day and night, so special instruments are employed to record these temperatures automatically. Such instruments are called **Maximum and Minimum Thermometers**. Six's Maximum and Minimum Thermometer (fig. 47) consists of a large bulb A full of alcohol and a small bulb B partly filled with alcohol. A mercury thread separates the two lots of alcohol. The instrument is really an alcohol thermometer, and when the liquid in the bulb A expands, it pushes the mercury thread in front of it. As the mercury rises in the left-hand side it pushes up a small steel index. When the maximum temperature has been reached, and the temperature begins to fall, the mercury thread goes down on the left-hand side but the index does not descend, as it is held against the side of the tube by a small spring, just strong enough to prevent it slipping; and the alcohol is able to flow past it. The mercury thread is highest on the right-hand side

when the temperature is lowest, so that the steel index in that side indicates the minimum temperature. The scale of temperature, which reads upwards on the left-hand side and downwards on the right, is graduated by

comparison with an ordinary thermometer. Obviously the two ends of the mercury thread must read the same temperature on each scale. The maximum and minimum temperatures are read by noting the scale reading level with the lower end of each index, and the instrument is re-set by tapping the indexes down.

### The Pyrometer.

Even the mercury thermometer cannot be used for temperatures above about  $350^{\circ}$  C., but it is often necessary to measure temperatures of  $1000^{\circ}$  C., or higher, in the furnaces of factories. One of the instruments

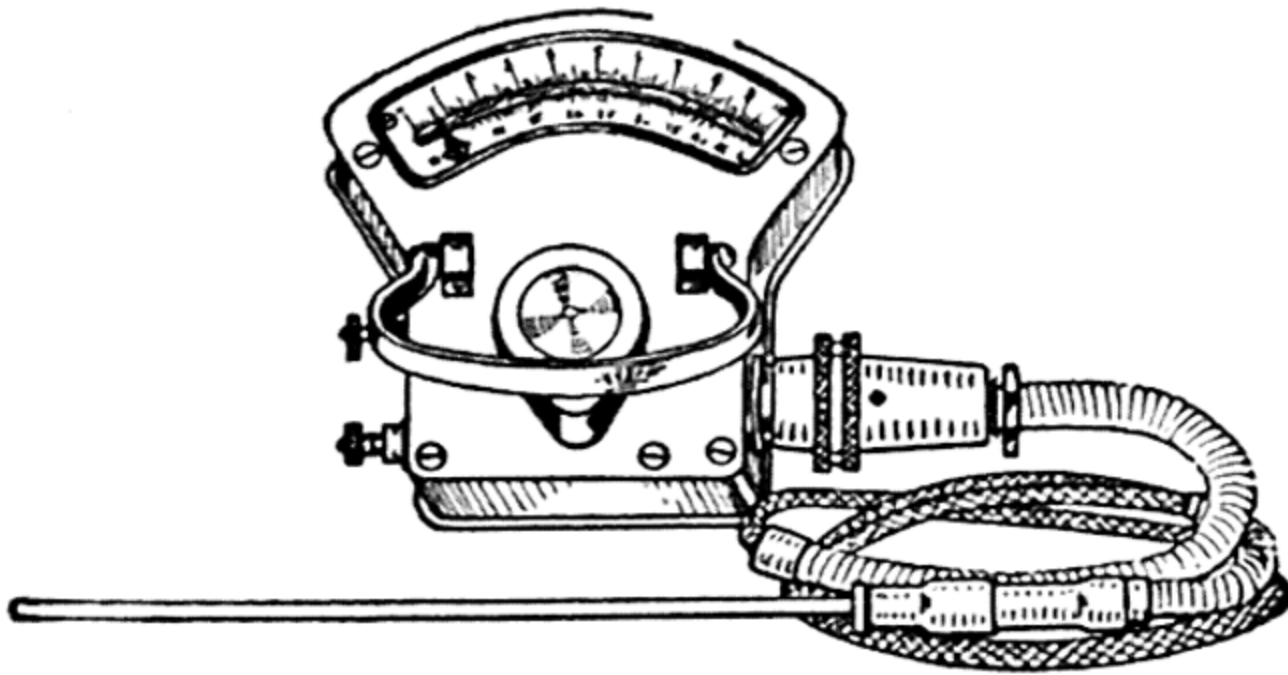


Fig. 48. — Pyrometer Indicating Outfit

used for this purpose is called a **pyrometer**, and depends on the fact that, if wires of two different metals are joined together at both ends and one of the ends is heated, a small electric current (a **thermo-electric current**) flows round the wires. The greater the temperature difference between the two ends the greater the current. The junction of the metals to be placed in the furnace is enclosed in a long thin cover of some heat-resisting substance, and the wires from this are led by insulated flex to the cold junction, one of the wires passing through a milliammeter on the way. The milliammeter measures the electric current flowing in

the wires, the value being indicated by a pointer moving over a graduated scale. By heating the hot junction to known high temperatures the scale of the milliammeter can be graduated to read directly in degrees of temperature, provided the temperature of the cold junction is always the same. This can be secured by putting the cold junction in oil at a fixed temperature, but if the instrument is used in a laboratory, the temperature of which varies very little, it is usually sufficiently accurate if the cold junction is merely exposed to the air. Such instruments will read up to about  $1400^{\circ}\text{C.}$ , above which temperature the heat begins to affect the wires.

### **The Transference of Heat — Conduction.**

If we place the end of a poker in the fire, and leave it there for some time, the other end gradually warms up until it is too hot to be held comfortably. Heat has travelled along the metal poker by conduction, each portion of the metal passing on the heat to the next. All substances will transmit heat by conduction, although some are much better conductors than others. If a silver spoon and a wooden spoon are both placed in a vessel of hot water, the handle of the silver spoon soon becomes hot while that of the wooden spoon does not. The same fact is shown very clearly by placing a sheet of paper round a compound cylinder, half brass tube and half wood (fig. 49), and holding the paper in the bunsen flame for a few seconds. Where the paper is in contact with the wood it will be found to be charred and black, but to be quite unaffected where it is in contact with the brass. The metal tubing is able to conduct the heat of the flame away so rapidly that the paper in contact with it is not heated to a sufficiently high temperature for it to char, but the wood, being a very poor conductor, allows the heat to accumulate in the paper and thus raise its temperature so high that it chars. Generally speaking, metals are the best con-

ductors of heat, although there is considerable variation even among metals. The varying conductivities of different metals can be shown by Ingenhousz's experiment. A metal trough (fig. 50) has a number of open-

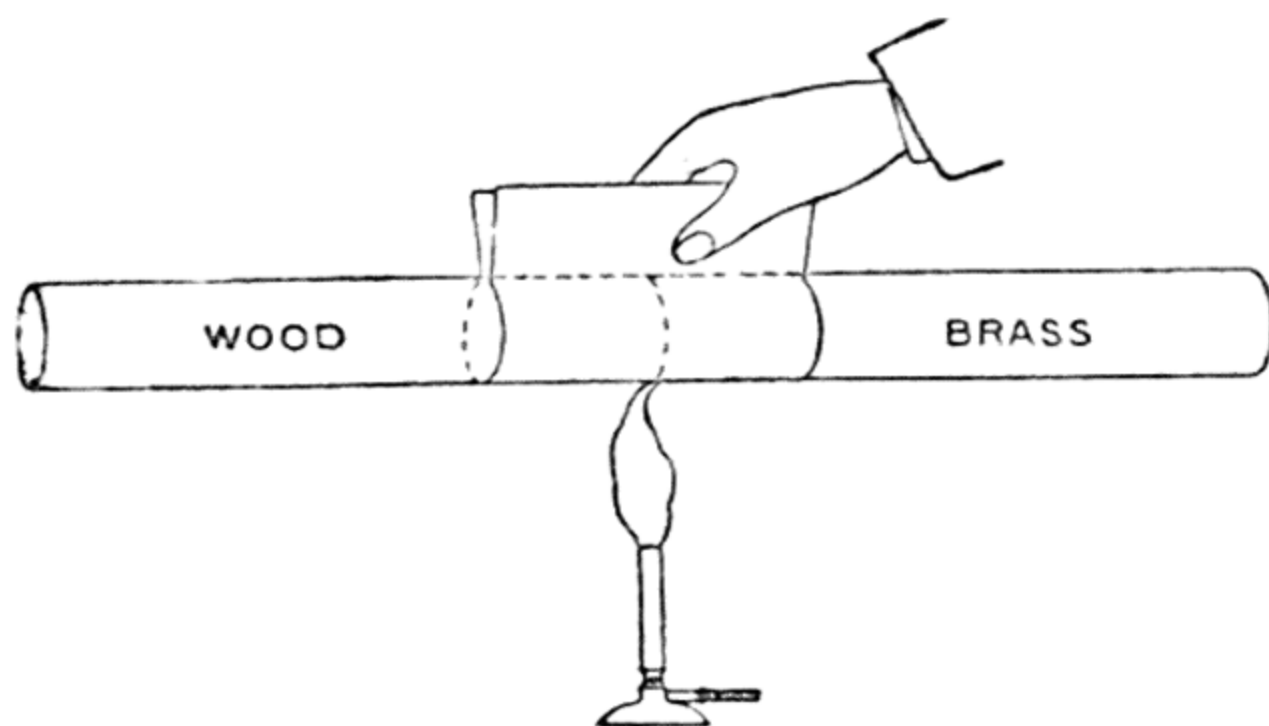


Fig. 49. — To show that wood is a poor conductor of heat

ings in one side into which are inserted corks through which are passed rods of various metals. The rods have been coated with paraffin-wax by dipping them in the molten wax. Boiling water is poured into the vessel

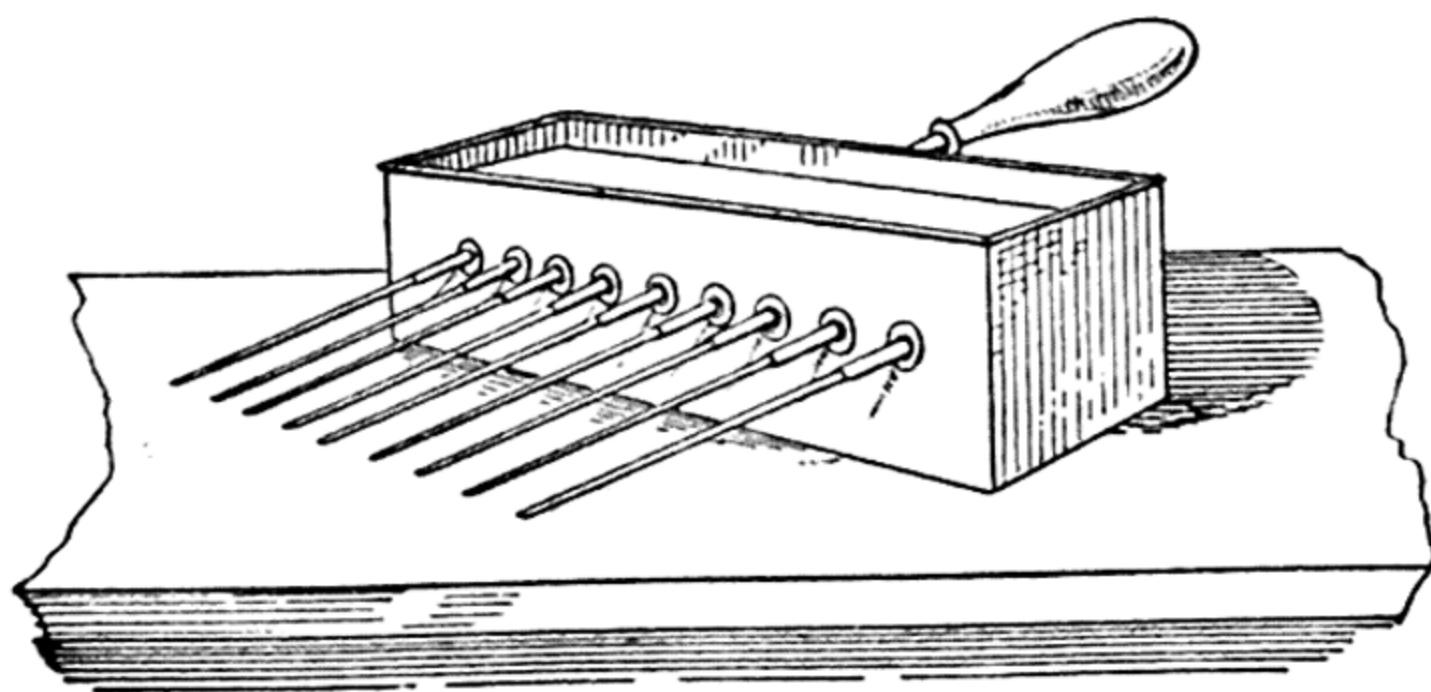


Fig. 50. — Ingenhousz's Apparatus

and, as the heat passes along the bars, the wax on them begins to melt. When no more wax melts it is found that it has melted much farther along the copper and aluminium rods than along the iron or lead.

With the exception of mercury, which is a metal, liquids are very poor conductors of heat. The poor

conductivity of water can be shown by taking a resistance-glass (e.g. "Pyrex") boiling-tube two-thirds full of water and heating the water at the top (fig. 51). When the surface water has been brought to the boil the water at the bottom of the tube still feels quite cool, because the heat of the flame has not been conducted downwards. Air and other gases are even poorer conductors than water.

THERMAL CONDUCTIVITIES OF COMMON SUBSTANCES  
COMPARED TO SILVER (= 1000)

Silver .. ..	1000	Cotton .. ..	0.55
Copper .. ..	920	Wood .. ..	0.50
Aluminium .. ..	500	Paper .. ..	0.30
Steel .. ..	110	Flannel .. ..	0.23
Mercury .. ..	18	Cork .. ..	0.10
Cement .. ..	7	Felt .. ..	0.09
Glass .. ..	2	Air .. ..	0.05
Water .. ..	1.4	Cotton-wool .. ..	0.04

We have all noticed in stepping out of a bath that a cork bath-mat feels much warmer than a linoleum floor.

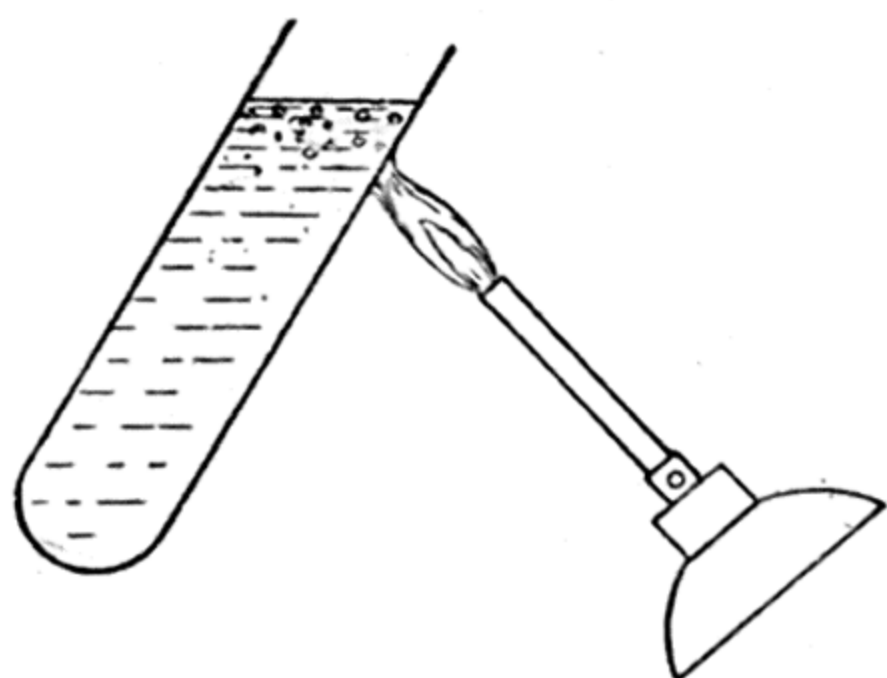


Fig. 51. — To show that water is a poor conductor of heat.

As we have already seen, the human body has a temperature of about 98° F., well above that of our surroundings, so that we are constantly losing heat from our bodies. The linoleum is a much better conductor of heat than the cork and so conducts the heat away from our feet much more rapidly. When we lose heat rapidly we feel the sensation of cold. This is another reason

why our senses are not a reliable guide to temperature, for of two bodies at the same temperature, colder than our hands, the better conductor feels the colder, while

of two bodies at the same temperature, hotter than our hands, the better conductor feels the warmer.

Poor conductors of heat are often useful. They are employed as lagging round steam pipes, water boilers, and heaters, especially electric water heaters, to prevent heat being lost to the air through the metal of the pipes or heater. Straw and sacking are put round exposed water pipes in frosty weather to prevent the water in the pipes losing so much heat that it freezes and bursts the pipes. The feathers of birds and the fur of animals are poor conductors that prevent too rapid a loss of heat from these organisms, which, like man himself, have a body temperature considerably above that of their surroundings. It is not surprising that the warmest fur, that is, the fur that allows least heat to pass through it, is to be found on animals living in the coldest climates. Man has no fur or feathers, but makes up for this by wearing clothes, varying in amount and thickness according to the climate. Clothes are made of such substances as wool, cotton, silk, and leather — all poor conductors — and many fabrics contain much air imprisoned between the threads, which considerably reduces their conductivity (see Table, p. 60, for conductivity of air). Cotton-wool is another substance that owes a good deal of its poor heat conductivity to the air it encloses, but perhaps the best example is eiderdown, which consists of the breast feathers of the eider-duck.

### Convection.

Despite the fact that water is such a poor conductor of heat, it is nevertheless very easy to put heat into a vessel of water in such a way that the heat is transferred to every part of the liquid. How is this heat transferred? The method is made clear by a simple experiment. A large beaker of water is heated by means of a small bunsen flame, and a crystal of potassium permanganate, or of magenta, is dropped into the

water and sinks to the bottom (fig. 52). The crystal immediately begins to dissolve, and the pinkish solution formed is seen to rise slowly up one side of the beaker, across the top of the water, and descend again down the other side. The coloured solution enables us to

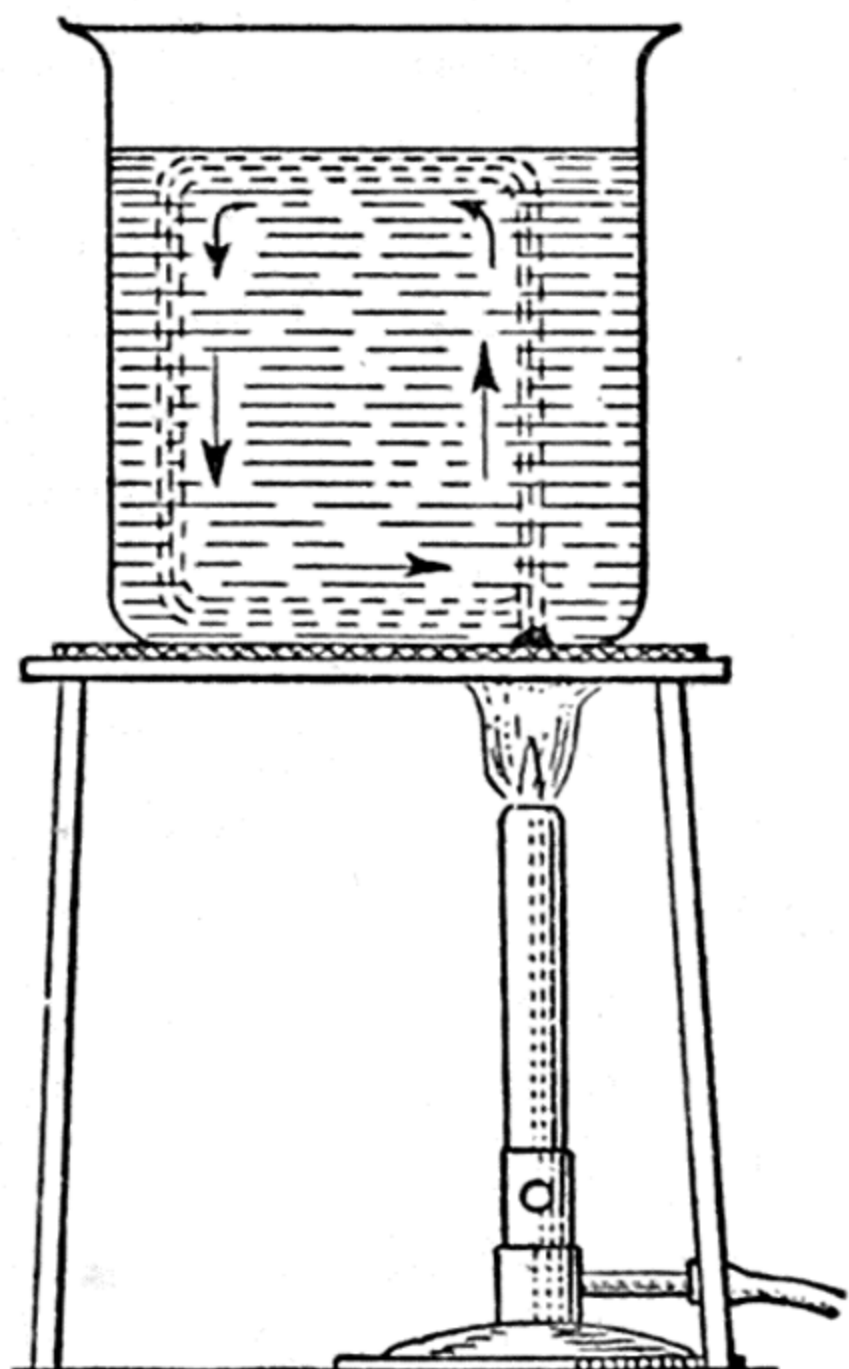


Fig. 52. — Convection Currents in Water

detect the presence of the currents in the water. The water on the right-hand side at the bottom of the beaker is heated by the flame, expands, and, so becoming less dense than the neighbouring water, is pushed upwards by the colder, denser water from the left-hand side, which takes its place as it rises. In this way a continuous circulation is set up that results in the whole of the liquid becoming heated.

✓ This method of heat transference, in which part of the substance heated itself moves, carrying heat with it, is called **convection**. Convection is possible only in liquids and

gases, because in solids the separate parts have no freedom of movement.

In the above experiment the heated liquid expands and therefore rises. When we were demonstrating the poor conductivity of water (fig. 51), we heated the water at the top, and the hot water, being lighter than the cold water below it, remained on top. Thus there were no convection currents to transfer the heat to the remainder of the liquid. Convection is by far the most important method of heat transference in liquids and gases.

Convection currents are made use of in the heating of buildings by hot-water pipes. The furnace to heat

the water is situated at the lowest point of the system, usually in a basement or cellar. The hot water rises by convection to the hot-water tank at the highest or farthest point in the circuit and returns through radiators to the

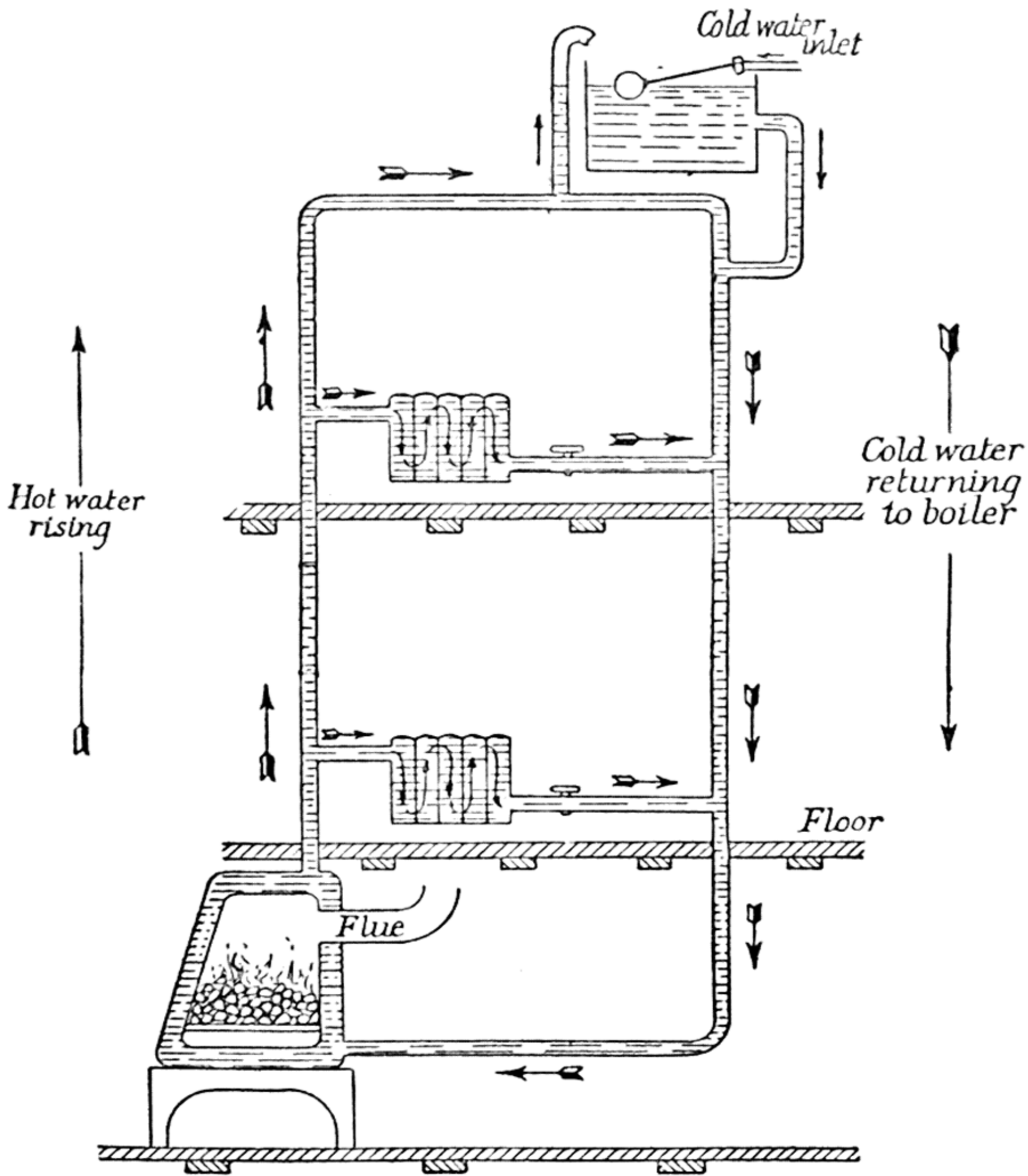


Fig. 53. — Diagram to illustrate a Central-heating System

boiler. An expansion tank has to be provided as the total volume of the water increases when it is heated, and the tank also acts as a safety valve should the water by any chance be heated to boiling-point instead of to about  $160^{\circ}$  F., the temperature normally used (fig. 53).

## Convection in Gases.

Convection in air is readily shown by the apparatus of fig. 54, which consists of a box fitted with a glass front and two lamp chimneys. A lighted candle is placed under one of the chimneys and a piece of smouldering paper or rag is held above the top of the other chimney. The smoke is drawn with surprising speed

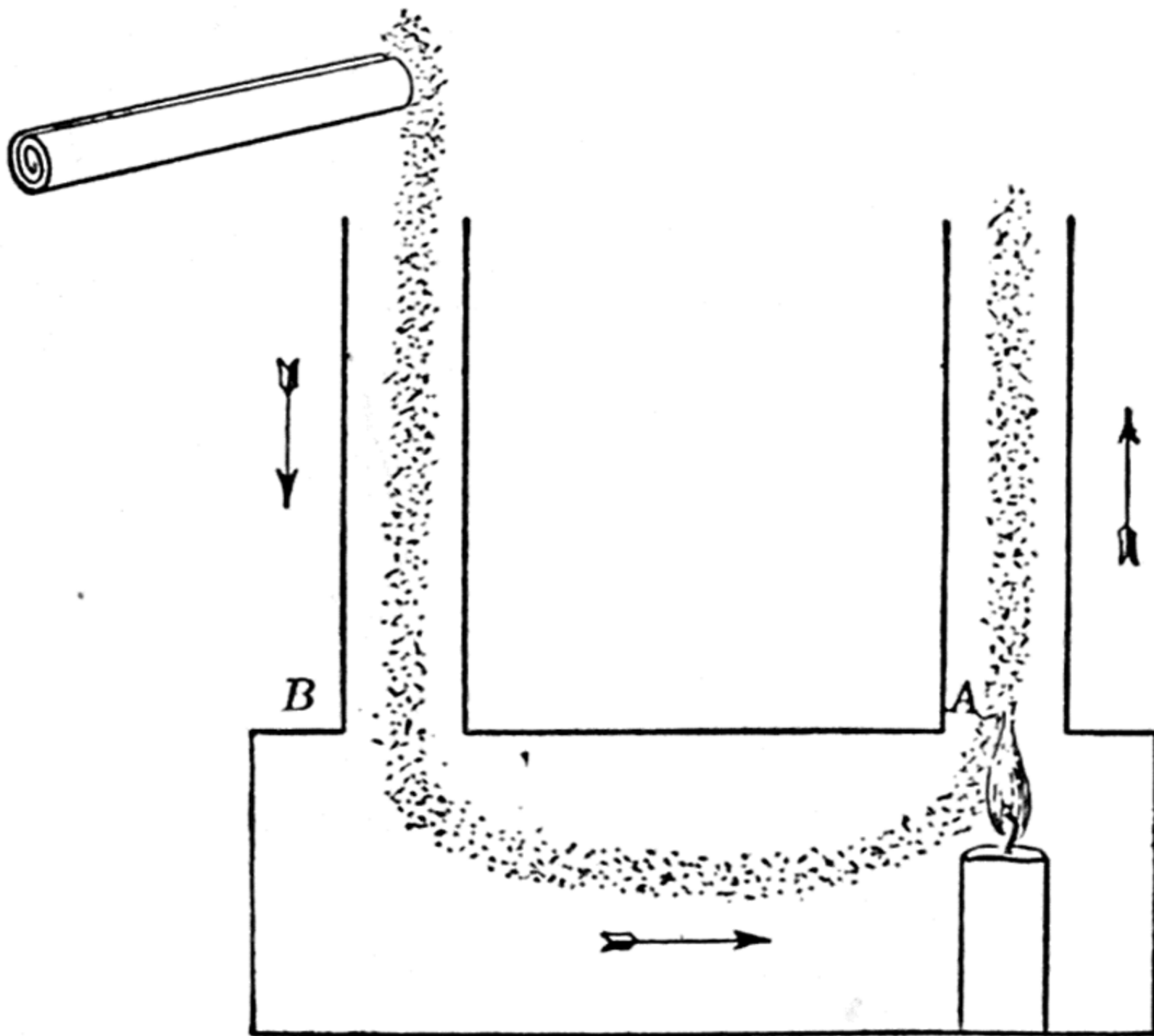


Fig. 54. — Convection in Air

down the one chimney and escapes up the other. The smoke merely renders visible the circulation of air due to the rising of the warm, less dense air heated by the candle flame. This apparatus is sometimes referred to as the “model coal-mine”, for in the early days ventilation of underground workings was secured by having a furnace at the foot of one shaft (called the “up-cast”), air being drawn down the other (or “down-

cast"). All coal-mines are compelled by law to have two shafts, which are used also for the cages conveying men and coal, but the circulation of air in mines is maintained in these days by the use of fans.

### **Ventilation.**

The ventilation of rooms is mainly brought about by convection. Warm, exhaled air rises, and will escape from a window open at the top, colder air entering the room from openings lower down, or else by a return current under the out-flowing one at the same window. In rooms heated by hot-water pipes the radiators are frequently placed under windows, so that the cold air entering at them may be warmed as it descends past the radiators. If there is a fire in a room, the current of hot air rising up the chimney continually draws in air from other parts of the room and fresh air enters the room from outside to take the place of the air rising up the chimney. The higher the chimney the stronger the convection current of air produced, so that tall chimneys are used in factories to give a powerful "draught" for the furnaces.

### **Winds.**

Winds are convection currents in the air on a large scale, due to differences of temperature and pressure over neighbouring parts of the earth's surface. A familiar example of this to dwellers on the coast is the occurrence of land and sea breezes. During the day the land is heated by the sun's rays much more than the adjacent sea. The air over the land becomes warmer than that over the sea, and convection currents are set up, the cooler, denser air from over the sea blowing landwards during the afternoon as a **sea breeze**. At night, on the other hand, the land cools down much more rapidly than the sea, so that at night we get the reverse effect, colder, denser air blowing from the land

to the sea as a **land breeze**. In each case there are probably return currents at higher levels. Land and sea

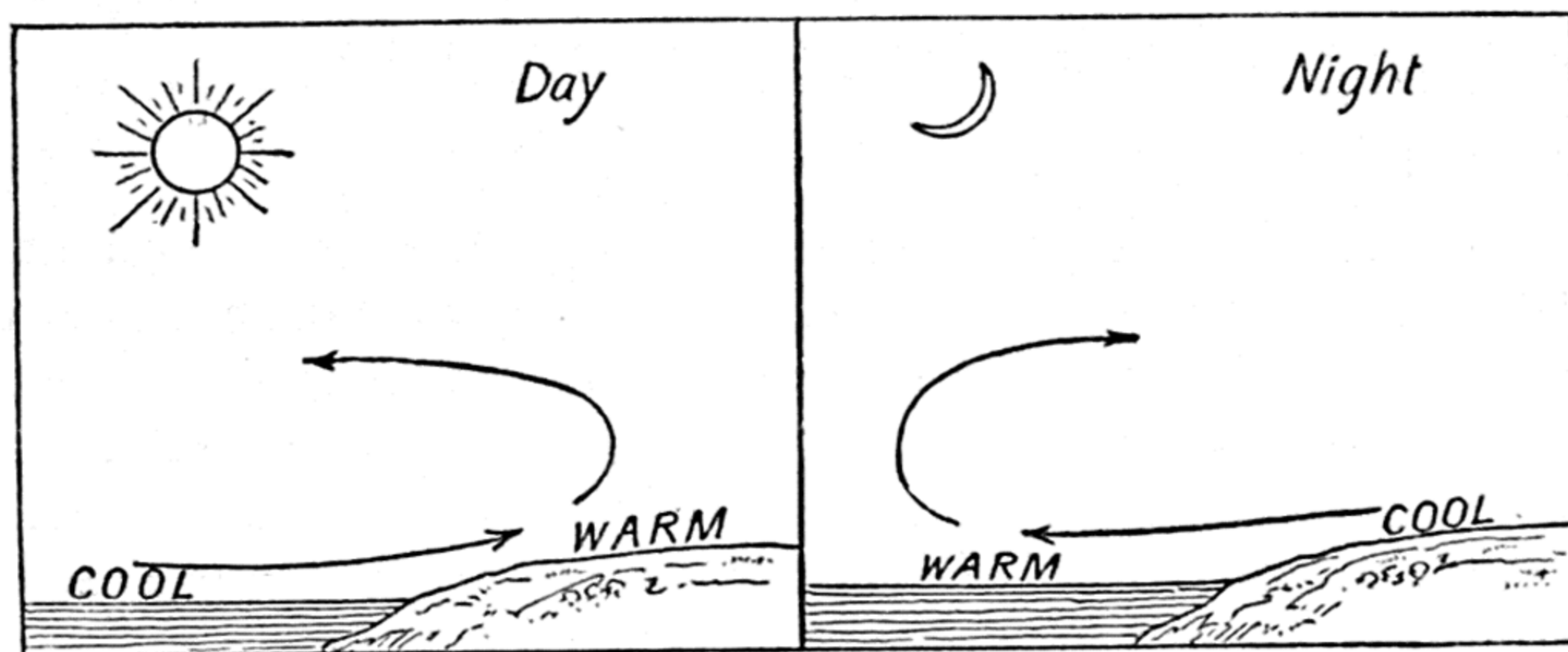


Fig. 55. — Land Breeze and Sea Breeze

During the day the warmth of the sun raises the temperature of the land above that of the sea.

At night the land cools down much more rapidly than the sea.

breezes are perceptible only within a very few miles of the coast and up to an altitude of about 200 feet.

### The Water-cooling of Engines.

In order to prevent the cylinders of a car becoming over-heated, they are surrounded by water, which circulates up past the hot cylinders and down the radiator, where it is cooled by the current of air caused by the motion of the car (fig. 56). Practically all cars have in addition a fan, worked off the engine, and this causes a current of air which helps to cool the water when the car is at rest or only moving slowly. In very cold weather the circulation of water in the radiator may be stopped by the choking of the connecting tubes with ice. If this happens the water round the cylinders quickly boils when the engine is running.

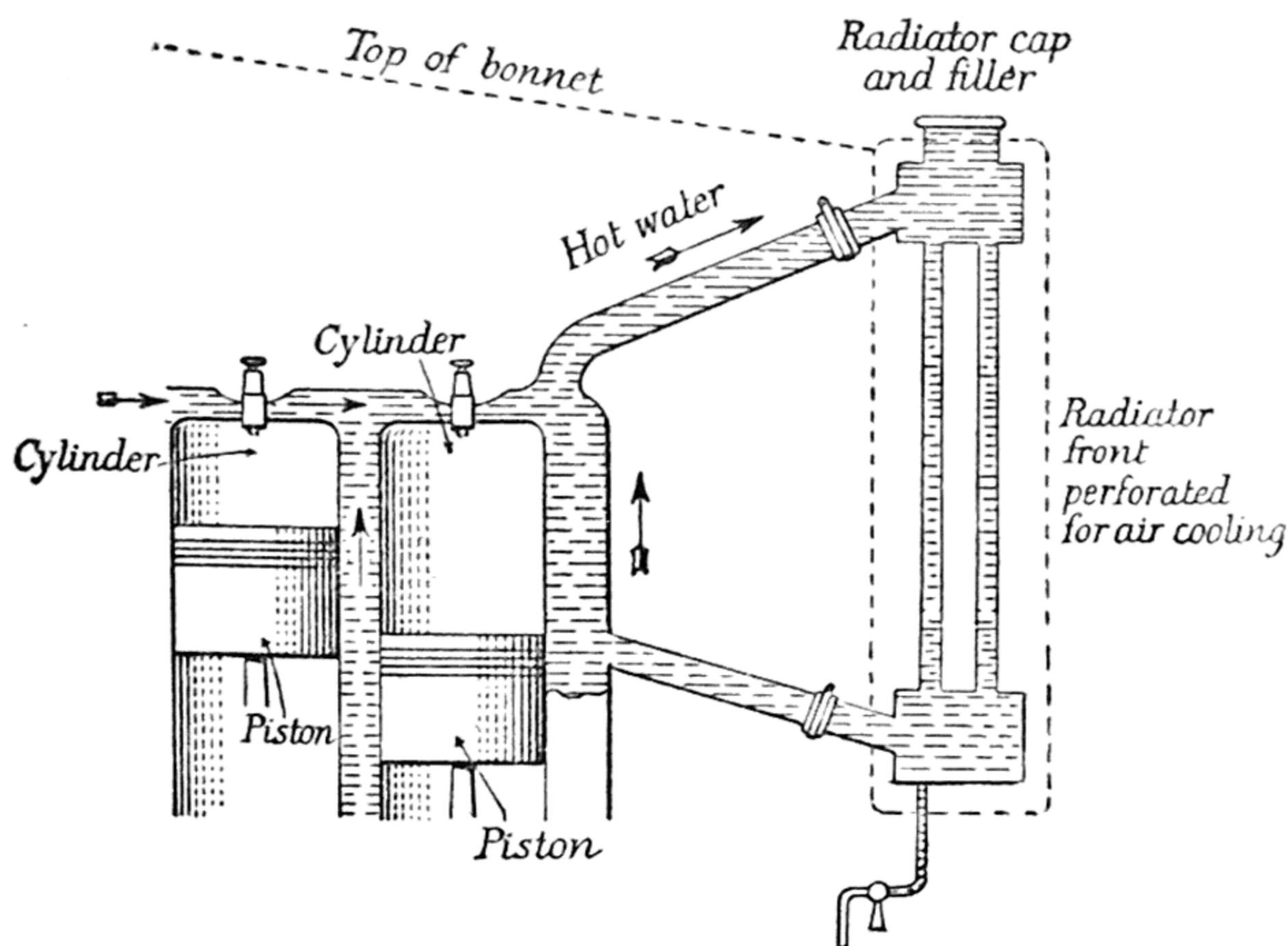


Fig. 56. — Diagram of Water-cooled Engine of a Car

## QUESTIONS

1. What do you mean by *temperature*? Is it the same thing as *heat*? What is the connection between these two?
2. Explain clearly how a thermometer works.
3. What do you understand by the term *a degree Fahrenheit*? Why do we need *two* fixed points in graduating a thermometer?
4. Describe the various effects produced by heat, and give one example of each.
5. Why must the ice be melting when the lower fixed point is found?
6. Convert the following Centigrade temperatures into the corresponding Fahrenheit temperatures:  $150^{\circ}\text{C.}$ ,  $50^{\circ}\text{C.}$ ,  $27^{\circ}\text{C.}$ ,  $-15^{\circ}\text{C.}$ ,  $-40^{\circ}\text{C.}$
7. Convert the following Fahrenheit temperatures into the corresponding Centigrade temperatures;  $113^{\circ}\text{F.}$ ,  $194^{\circ}\text{F.}$ ,  $0^{\circ}\text{F.}$ ,  $-9^{\circ}\text{F.}$
8. In what ways may heat be transferred from one body

to another? State briefly how these modes of heat transference come into operation when a building is heated by a hot-water system. L.

9. What do you understand by the phrase " a temperature of  $100^{\circ}$  *in the sun* " ? Why is a temperature taken in the sun higher than one taken at the same time in the shade?

10. Why do metal teapots often have a wooden handle?

11. Explain the following statements:

(a) For ventilating a room it is better to open a window at the top than at the bottom.

(b) An open fire is a good aid to the ventilation of a room.

(c) A glass stopper which has become fixed in the neck of a bottle can often be released by warming the neck gently.

## CHAPTER V

### INTRODUCTORY LIGHT

✓ We cannot see in the dark, but when we switch on the light the lamp gives out light and we are able to see, not only the lamp itself, which is said to be **luminous**, a source of light, but other objects also. These latter are **non-luminous**, but become visible because they are able to reflect to our eyes light that has fallen on them from the lamp. On a bright sunny day we may see beams of sunlight shining through the window of an otherwise dimly-lighted room. We see these beams because air contains innumerable particles of dust floating in it, and these tiny particles reflect some of the light to our eyes. If we hold a lighted taper in the beam for a few seconds, we notice a dark space in the beam where all the dust particles have been burned away.

Notice that light is able to pass through some substances, such as glass, substances that we call **transparent**, but not through others that we call **opaque**. The precise nature of light, what it is, need not concern us for the present. It will be sufficient for us to consider only what it *does*.

The beams of light from the headlamps of distant cars, and the straight edge of sunbeams, suggest to us immediately that **light travels in straight lines**. This fact is very easily verified by taking three pieces of cardboard, each with a small hole in the centre, arranging them a foot or two apart in front of a lamp, and then adjusting the position of the holes until the lamp is

visible through them all. The three holes are now found to be in a straight line. Everyone knows that “you cannot see round corners”, which is another way

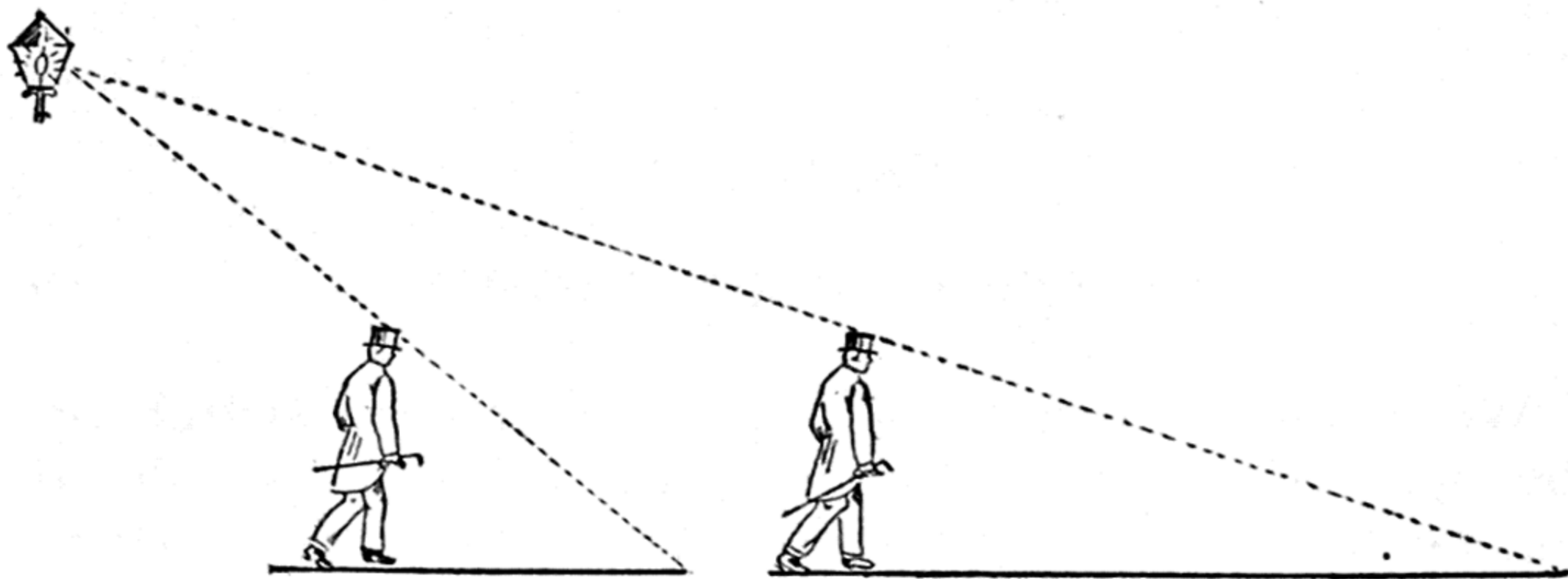


Fig. 57. — Light travels in straight lines

of stating the same fact. Further evidence is to be found in the formation of shadows. As we walk along the road at night our shadow lengthens when we walk away from a lamp, and the explanation is obvious if

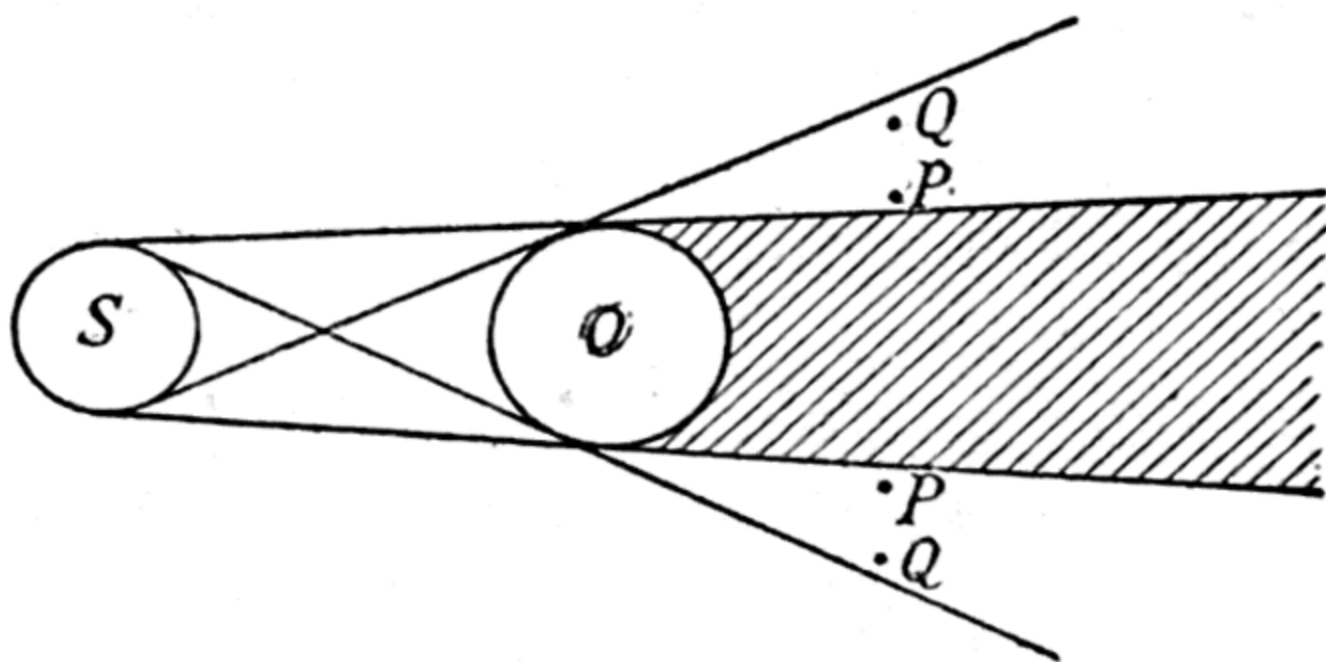


Fig. 58. — S represents a spherical source of light, and O a spherical obstacle. The shaded part of the shadow is the umbra.

we think of the light rays travelling in straight lines (fig. 57).

When the source of the light has an appreciable size compared with the object throwing the shadow, the whole of the shadow is not equally dark. Fig. 58 illustrates the case where the source of light is smaller than

the obstacle.  $S$  represents a spherical source of light and  $O$  a spherical obstacle. At all points in the shaded space behind  $O$  no part of the source is visible, so that there is no light at all in the space, which is in complete shadow. This part of the shadow is called the **umbra**. At points such as  $P$ , a little of the source of light is visible, but not all of it, so that  $P$  is in partial shadow or **penumbra**. As we move from  $P$  towards  $Q$ , more and more of the source is visible, so that in the penumbra the amount of light increases as we move towards its outer edge.

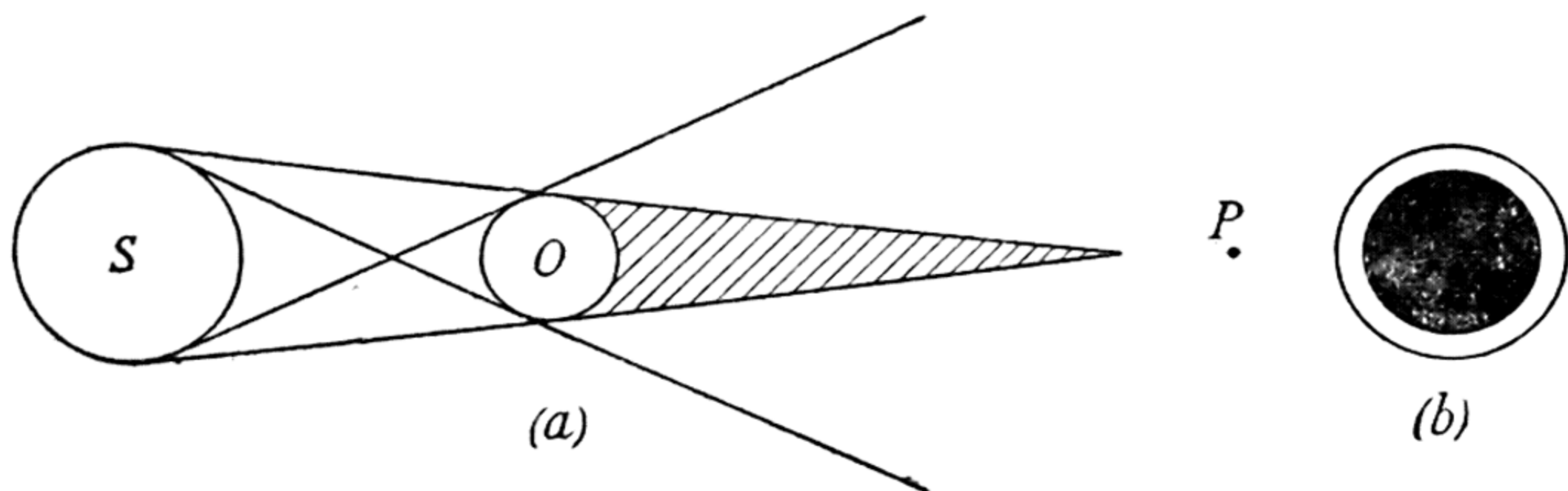


Fig. 59. — (a)  $S$  represents a spherical source of light, and  $O$  a spherical obstacle; (b) represents the appearance of the source as seen from  $P$ .

When the source of light is larger than the obstacle, although the penumbra increases in size as it gets farther from the obstacle, the umbra diminishes in size (fig. 59). The umbra forms a cone with its vertex on the side of the obstacle away from the source of light. At the point  $P$ , beyond the vertex, the obstacle is too small to hide the whole of the source, which overlaps all round the obstacle to give the appearance of a ring of light.  $P$ , therefore, is part of the penumbra.

**EXPERIMENT 10. — To show the formation of umbra and penumbra.** Place a sheet of paper immediately below a pearl electric lamp bulb and hold between them an opaque sphere on a handle (the insulated brass spheres used in elementary electrostatics are suitable for this purpose). Hold

the sphere two or three feet above the paper and notice the penumbra shadow on the latter. Slowly lower the sphere and observe how the size of the penumbra diminishes, and how, at a certain distance, the darker shadow of the umbra appears in the centre of the penumbra and increases in size as the obstacle is brought nearer to the paper.

## Eclipses.

Eclipses of the sun occur when the moon passes between the sun and the earth, and, similarly, eclipses of the moon when the earth passes between the sun and the moon. The sun is an enormous sphere of

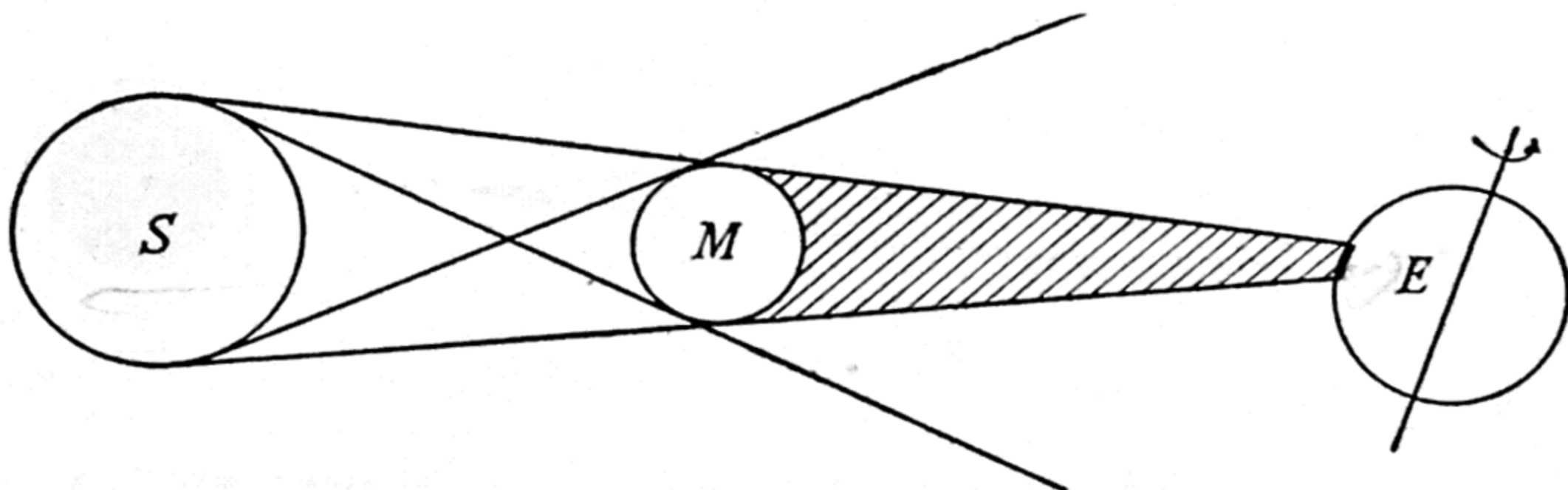


Fig. 60. — An Eclipse of the Sun

The eclipse is observed as total at that part of the earth shown in heavy line. Not to scale

white-hot gas around which the earth revolves in space in an almost circular orbit with a radius of about 92,000,000 miles, each revolution taking a year. The moon is a solid sphere, similar to the earth, although without an atmosphere, and rotates round the earth once in twenty-eight days, at a distance of about 240,000 miles. The diameters of the sun, earth, and moon are as 400 : 4 : 1.

The cone of umbra from the moon only just reaches the earth (fig. 60), so that over only a small portion of the earth's surface is the sun completely hidden by the moon; hence, a total eclipse is observed over only this small portion. The rest of the hemisphere of the earth

facing the sun is in penumbra, so that a partial eclipse is seen, and the farther away from the area of totality the greater the proportion of the sun's area that is visible. The last total eclipse of the sun visible in this country was in 1927, when the eclipse was total over a belt about sixty miles wide stretching across England from North Wales to Yorkshire. The next total eclipse visible in this country will be in 1999.

The moon, unlike the sun, is not self-luminous, the light we receive from the moon being merely the reflection of the sun's rays falling upon it. When the moon,

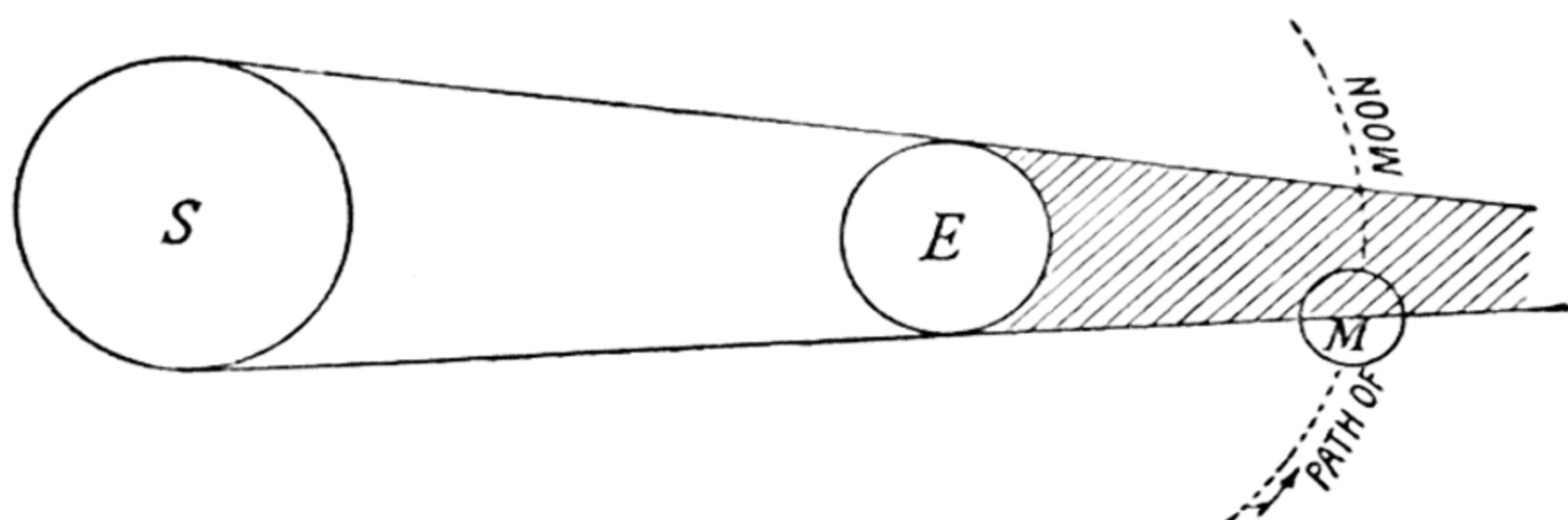


Fig. 61. — Eclipse of the Moon  
Moon entering earth's umbra. Not to scale

rotating round the earth, passes into the earth's umbra, the sun's rays are cut off from it and we observe an eclipse of the moon (fig. 61). Since the earth is so much larger than the moon the earth's umbra is more than twice the diameter of the moon at the distance of the moon, so that an eclipse of the moon lasts much longer than an eclipse of the sun. The shadow that we see creeping across the moon's surface is the circular edge of the cone of the earth's umbra. We do not notice much difference in the moon's appearance when it is in the earth's penumbra.

Since the moon rotates round the earth once a month, we should expect to have an eclipse of both the sun and the moon once a month. That eclipses are much less common than this is due to the fact that the moon's

orbit round the earth is in a slightly different plane from that of the earth round the sun, so that usually when the earth is between the sun and the moon, or the moon between the sun and the earth, these three bodies are not in a straight line.

### Reflection.

Every schoolboy knows how to reflect the light of the sun by means of a piece of mirror, thus altering the direction of the rays of light. The most convenient apparatus for demonstrating how rays of light behave when they are reflected is the so-called "ray-box". Many forms of ray-box can be obtained, but in essentials they all consist of a small and powerful electric lamp in some form of lamp-house, together with a lens and a gate or comb of metal with one or more narrow slits as required. By means of this apparatus it is possible to obtain powerful narrow beams of light which we will call "rays".

✓ **EXPERIMENT 11. — To investigate the laws of reflection.** A strip of plain mirror is placed along the  $0^\circ - 0^\circ$  diameter of a protractor card, and a ray of light from the ray-box adjusted to fall on the mirror at the centre of the card. The line perpendicular to the plane of the mirror at the point where the incident ray meets the mirror is called the **normal**. The angles which the incident and reflected rays make with this normal are called respectively the **angle of incidence** and the **angle of reflection**. Note that when we say that a ray is incident on a surface at an angle of  $20^\circ$ , we do not mean  $20^\circ$  measured from the surface, but from the normal to the surface. The incident and the reflected rays are clearly visible on the surface of the protractor card, and we can read off the angles of reflection corresponding to various angles of incidence. We find that **the angle of reflection is equal to the angle of incidence**. Notice also that the incident ray, the reflected ray, and the normal at the point of incidence are all in the plane of the protractor card. If we tilt the mirror so that the latter line is no longer in this plane, the reflected ray will no longer be in it. That is, **the incident and reflected rays are in the**

**same plane as the normal at the point of incidence.** The two statements in heavy type are called the laws of reflection.

We can now explain why some surfaces act as mirrors while others do not. Fig. 62 (b) represents a surface that is irregular. The rays of light falling on it are all parallel, but owing to the unevenness of the surface the normals for each ray at its point of incidence are not parallel, and so the reflected rays, instead of being parallel, are scattered in different directions. In fig. 62 (a)

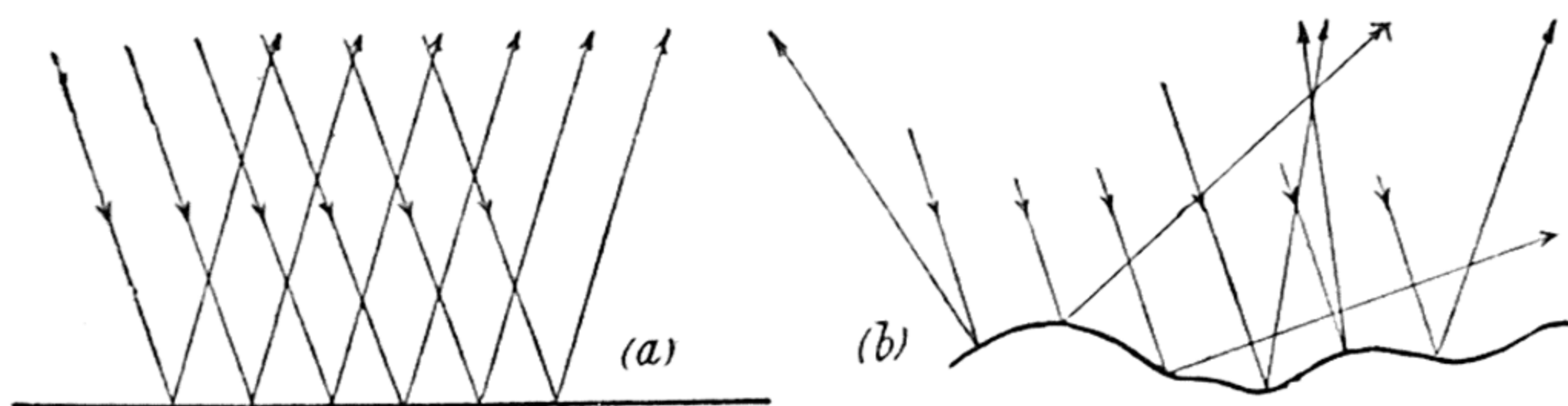


Fig. 62. — Laws of Reflection

(a) Regular reflection of parallel beam of light at smooth surface; (b) irregular reflection of parallel beam of light at irregular surface.

the surface is regular, and parallel rays falling on it remain parallel after reflection. This latter surface acts as a mirror, while the former does not. Even an irregular surface will act as a mirror if the incident rays are very oblique. (Draw a diagram and see why this is.) If you place your eye almost level with the top of a table or laboratory bench, quite a good reflection of the windows can be seen. Any regular surface can act as a mirror, even if the material is transparent. When it is dark out of doors, the windows of a brightly lighted room reflect a lot of light back into the room. They really reflect as much in the daytime, but so much light comes through from outside that the reflected light is not seen. We have all noticed the brilliant reflection of the windscreen of an approaching car when the angle is just right for the sun's rays to be reflected from it

into our eyes. Polished or glazed surfaces reflect much better than unpolished or unglazed surfaces. The paper used for books is generally somewhat glazed, so that a certain amount of light is reflected regularly. If a book is held in such a direction that incident light is reflected into the eye, we notice the glare, and the book can be read much more comfortably if it is held in a slightly different position. In many modern schemes of lighting, the light is thrown upwards on to a matt (unglazed) white surface, from which it is **diffused** or scattered in all directions. This avoids direct glare from the lamps and also the formation of sharp shadows.

The mirrors in everyday use consist of plate glass with a backing of mercury amalgam. A little of the light falling on the glass is reflected at the front surface, but most of it passes through the glass and is reflected at the silvered surface. If you hold a candle in front of a mirror of this kind, and look into the mirror obliquely, you can see the faint reflection of the flame at the surface of the glass as well as the much brighter reflection in the silvering. The appearance or reflection of an object in a mirror is called an **image**.

### ✓ **The Formation of an Image.**

It is quite easy to explain the way in which such an image is formed. Let  $O$  (fig. 63) represent an object, and let  $OP$ ,  $OQ$  be two rays of light from the object falling on the mirror at  $P$  and  $Q$  respectively. These rays are reflected in accordance with the laws of reflection and enter the eye,  $E$ , of the observer. The eye is unable to detect the change in direction of the rays that occurs when light is reflected, so that the rays appear to the eye to have come from  $I$ , the image of  $O$ . The rays  $OP$ ,  $OQ$  form a **diverging beam** (or **pencil**, as it is more usually called) and the pencil is still diverging after reflection. It is clear that the diverging rays entering the eye and producing the appearance of an

image at  $I$  have not actually passed through  $I$ , but merely appear to the eye to have done so. An image formed in this way by rays that have not actually passed through the image is said to be a **virtual image**.

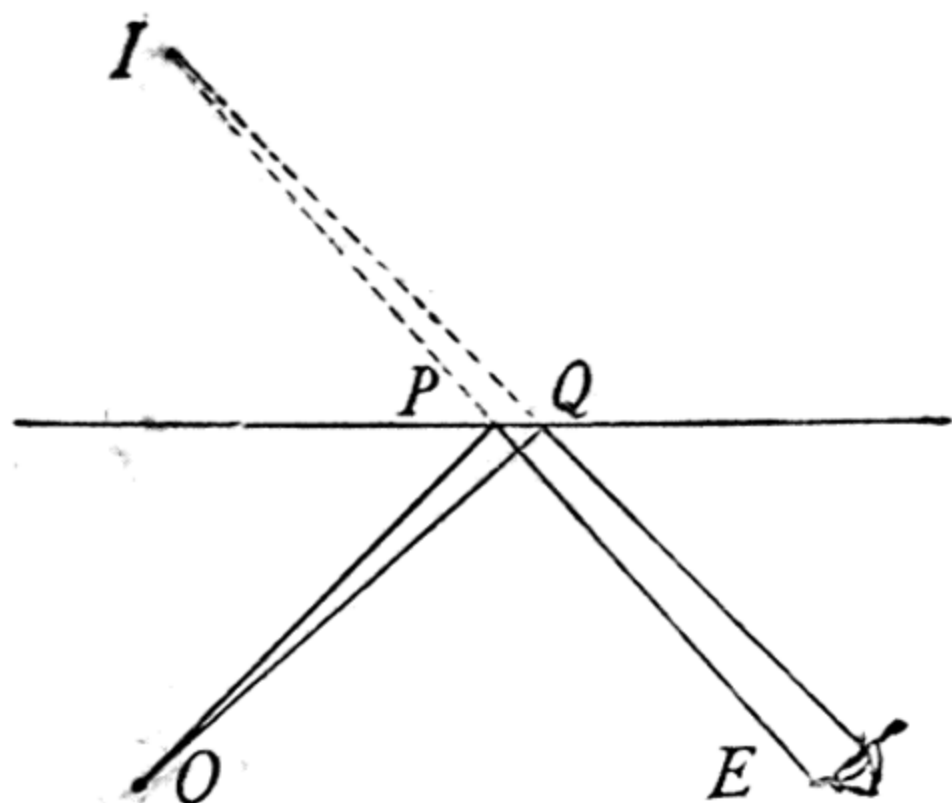


Fig. 63. — Formation of Image by Reflection in a Plane Mirror

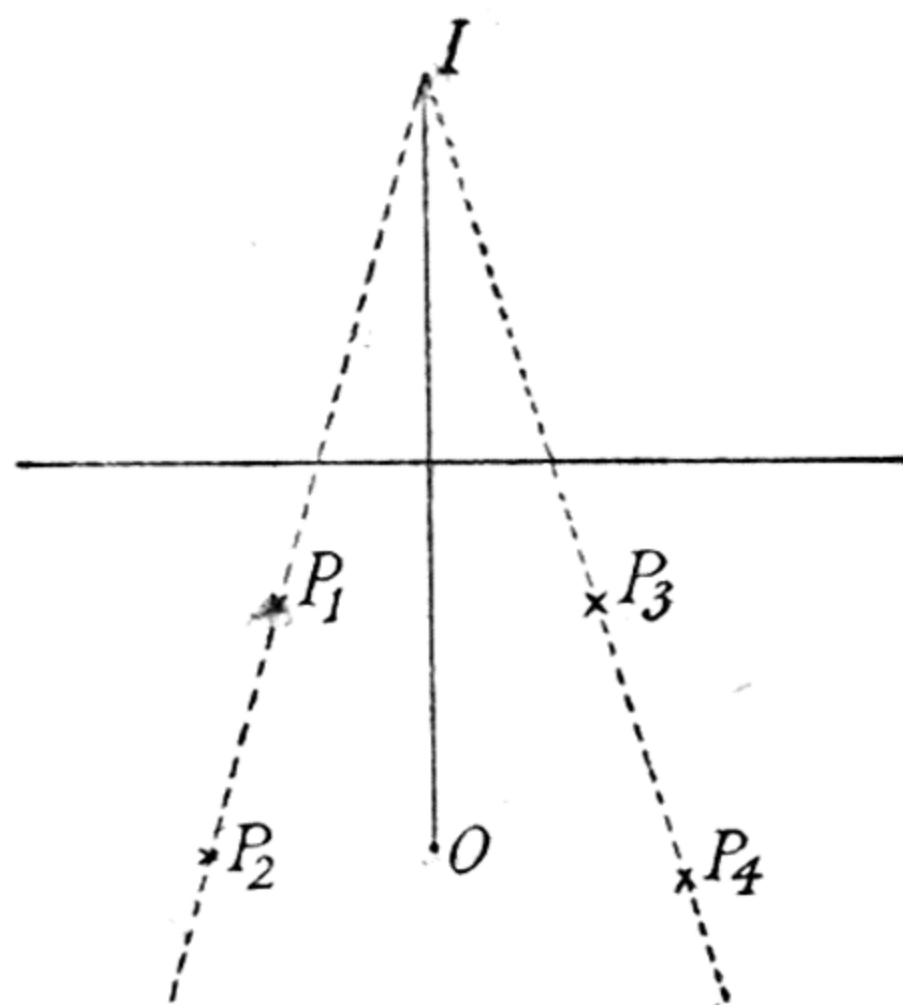


Fig. 64. — Position of Image in Plane Mirror

**EXPERIMENT 12. — To find the position of an image in a plane mirror. (Method 1.)** Pin a sheet of drawing paper on to a board. (A very suitable board can be made by stiffening cork table mats with a backing of five-ply.) Place a strip of plane mirror on the paper, and mark the position of the reflecting surface by drawing a thin pencil line on the paper at the *back* of the mirror. Stick a pin,  $O$ , in front of the mirror, to act as an object (fig. 64). Now look into the mirror and fix two pins  $P_1$ ,  $P_2$ , in the board so that they appear in line with the image  $I$ . Look into the mirror from another position and again put pins  $P_3$ ,  $P_4$ , in line with  $I$ . Remove the mirror and pins, and with the aid of a ruler draw the lines  $P_2$ ,  $P_1$  and  $P_4$ ,  $P_3$ , producing them until they meet at  $I$ . Since the image lies on both of these lines, it must be where they intersect, that is, at  $I$ . Join  $OI$ , and measure (*a*) the distance of  $O$  from the mirror, (*b*) the distance of  $I$  from the mirror, and (*c*) the angle  $IO$  makes with the mirror. Repeat the experiment for several different positions of  $O$ . From the result it will be seen that (1) the image is as far behind the mirror as the object is in front, and (2) the line joining the image and object is at right angles to the mirror.

## Parallax.

Suppose we have two objects A and B. By placing the eye at  $E_1$  (fig. 65), we can arrange so that the two objects appear superposed.

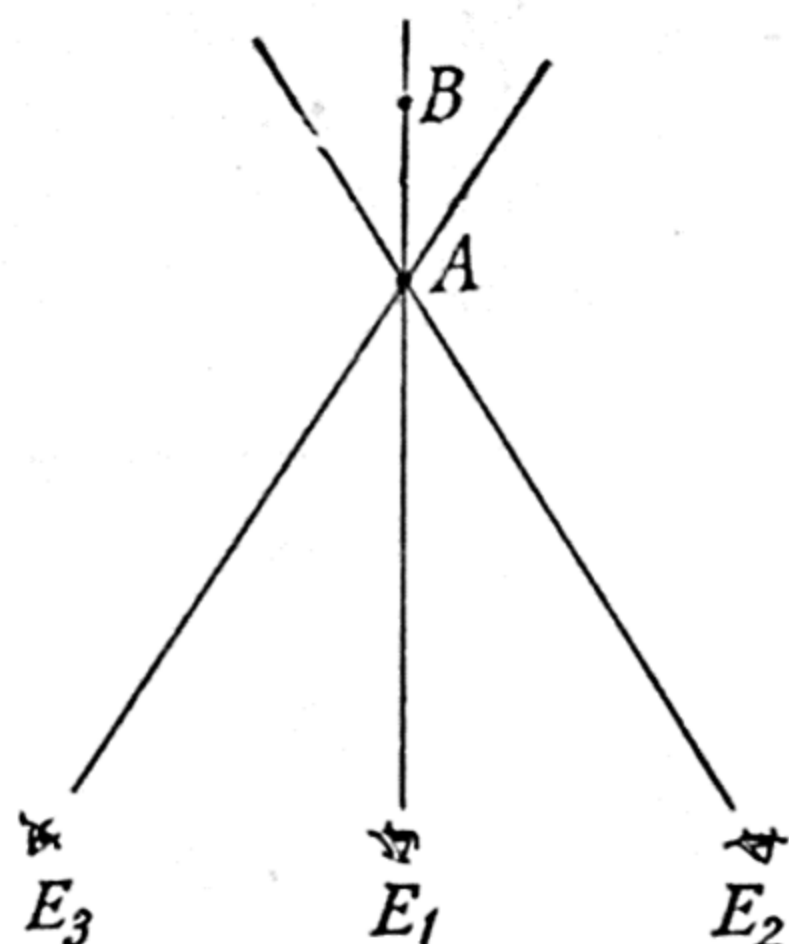


Fig. 65. — Parallax

A appears in line with B when viewed from  $E_1$ , to the right of B when viewed from  $E_3$ , and to the left of B when viewed from  $E_2$ .

If the eye is moved to the right, to  $E_2$ , the more distant object B now appears on the right of the nearer one, and if the eye is moved to the left, to  $E_3$ , the more distant object now appears to the left of the nearer one. Note that in each case that object that is farther from the eye appears to be on the side of the nearer one to which the eye has been moved. This apparent difference in relative positions of the two objects as the position of the observer changes is called **parallax**. The closer A and B are together the less they appear

to separate as the position of the observer's eye changes, and if A and B coincide they will not appear to separate at all but will appear coincident from all positions.

**EXPERIMENT 13. — To find the position of an image in a plane mirror. (Method 2.)** Arrange a sheet of drawing-paper, a mirror, and a large object-pin, as in Experiment 12. Stick another large pin in the drawing-paper behind the mirror. On looking into the mirror with the eye level with the drawing-board, the reflection of the shank of the object-pin can be seen and, projecting above the mirror, the top of the other pin. Adjust the position of the latter until it appears to be a continuation of the image in the mirror however the eye is moved. This can be done as follows: keeping the position of the eye fixed, insert the second pin behind the mirror so that it appears to be a continuation of the image. Move the eye

to the *right*. If the pin and the image separate, they are at different distances from the eye. Suppose the pin now appears to the *right* of the image. Then the pin is farther from the eye than the image. Move the pin, therefore, nearer the eye, and repeat the above procedure until finally there is no separation of pin and image when the eye is moved. Since there is no parallax between them, they are now coincident, and the position of the pin is also the position of the image. Remove the mirror and draw the line joining the two pins. Proceed as in Experiment 12 above.

### Nature of Image in a Plane Mirror.

Certain other facts about the image in a plane mirror are easily discovered. It is obvious that the image is **erect**, i.e. the same way up as the object. When we look into a mirror and close our *right* eye, it is the *left* eye that closes in the reflection. When we hold up the palm of our right hand to the mirror the image appears to be a left hand, and we are unable to read the reflection in a mirror of a line of writing because the writing in the image runs from right to left, instead of from left to right, which is the way we are accustomed to read it. This transposition of the right and left sides in the image is called lateral inversion. Finally, the image is the same size as the object. This can be shown by placing a mirror on a sheet of paper, drawing a pencil line in front of the mirror, and finding the position of each end of the image by the method of Experiment 12. The length of the image can then be measured and compared with that of the object line.

To sum up, the image in a plane mirror is: —

1. Virtual.
2. As far behind the mirror as the object is in front.
3. On the same normal to the mirror as the object.
4. Erect.
5. Laterally inverted.
6. The same size as the object.

**The Periscope.**— This instrument is used to enable one to see over the top of a trench without exposing oneself, or to view a procession over the heads of people

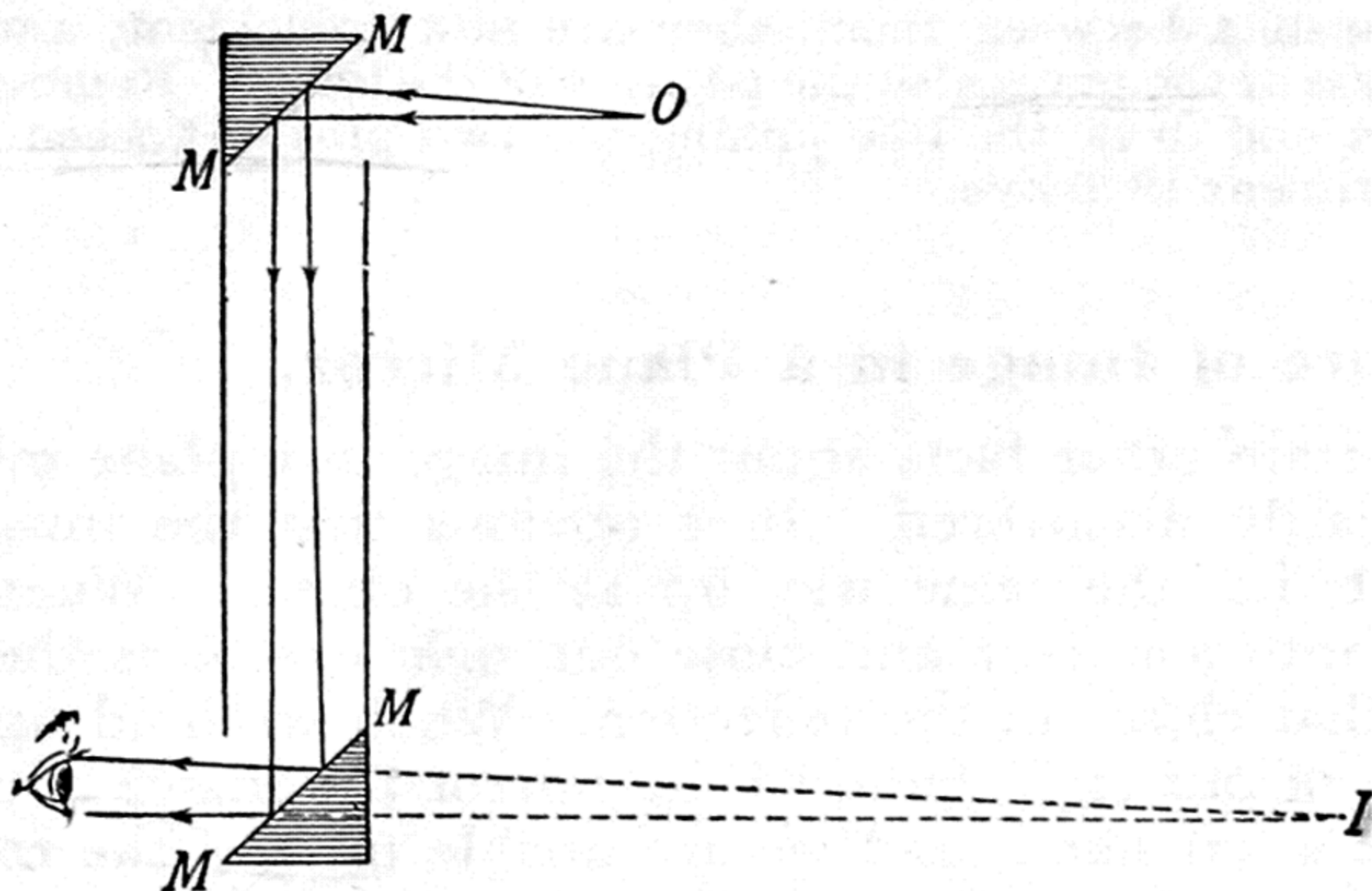


Fig. 66. — Principle of the simple periscope

in front. The way in which it works will be clear from the diagram (fig. 66).

The periscope of a submarine is much more complicated, but depends on the same principle.

### Reflection at Curved Surfaces.

The most commonly occurring curved mirrors are spherical in shape, that is, are parts of the surface of spheres. Those in which the reflecting surface is in the form of a hollow are called **concave**, while those in which the mirror bulges out are called **convex**. The mid-point of the mirror is its **pole**, and the centre of the sphere of which it forms a part is called its **centre of curvature**. The straight line obtained by joining the pole and the centre of curvature is called the **principal axis**.

**EXPERIMENT 14. — To show reflection of parallel rays of light at concave and convex mirrors.** Arrange a ray-box with a multiple slit, and adjust the apparatus so that the resulting rays of light are parallel. Allow them to fall on a concave mirror in a direction parallel to the principal axis CP of the mirror (fig. 67, *a*). After reflection, the rays of light converge

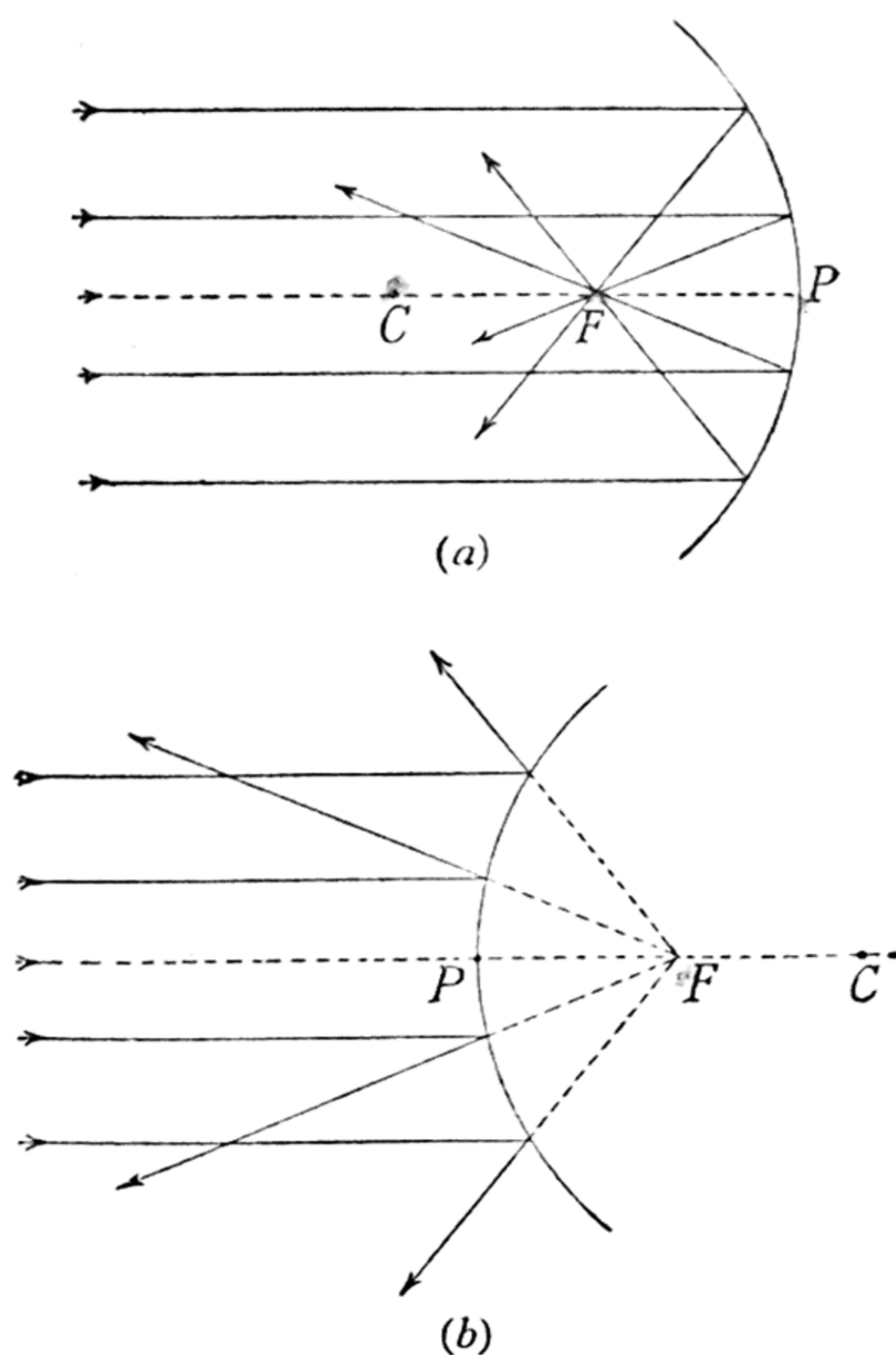


Fig. 67. — Reflection at Concave and Convex Mirrors

to a point on the principal axis midway between the pole and the centre of curvature. This point, F, is the **principal focus**, and the distance PF is called the **focal length** of the mirror. After passing through F the rays diverge again. A convex mirror causes the reflected rays to diverge. If the incident rays were parallel to the principal axis, the reflected rays would all diverge as though they had come from a point midway between P and C — the principal focus (fig. 67, *b*).

Now adjust the incident rays so that they are diverging or converging. They are again brought to a focus by the concave mirror, but no longer at the principal focus. ✓

Students sometimes imagine that the laws of reflection are different when light is reflected at curved surfaces from what they are when it is reflected at plane surfaces, but this is not so, and the paths of the reflected rays in the above experiment can easily be shown graphically to follow from the laws stated on p. 75.

With centre  $C$ , and any convenient radius, describe the arc of a circle to represent the mirror (fig. 68).

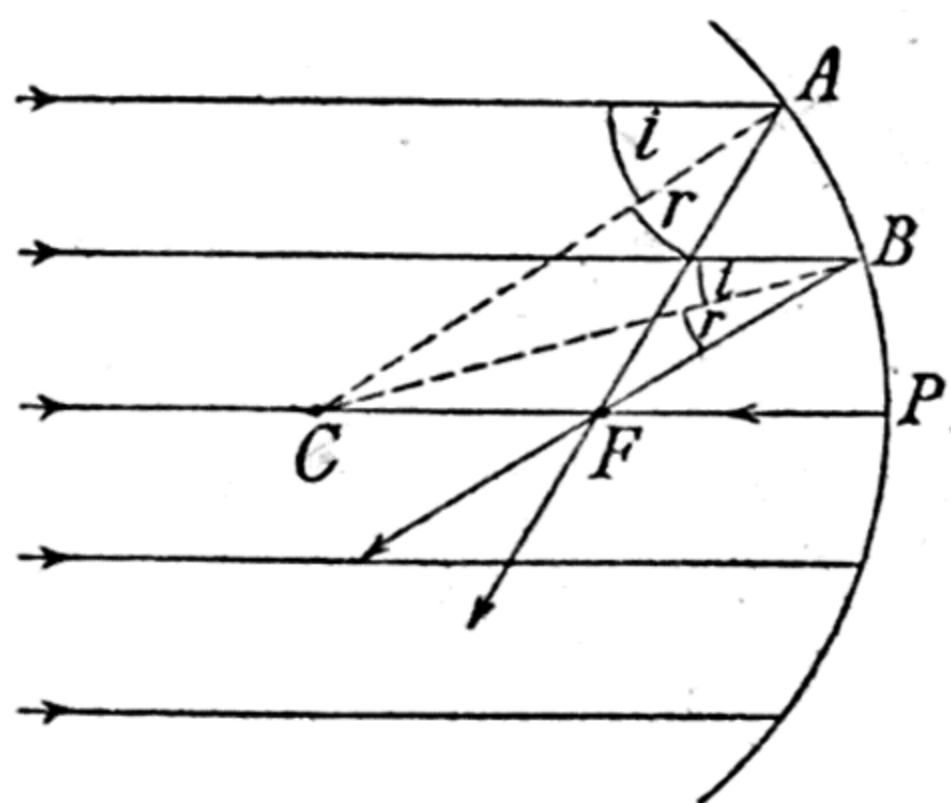


Fig. 68. — Principal Focus of Concave Mirror

$C$  is the centre of curvature and  $P$  the mid-point of the mirror. Draw three or four rays parallel to the principal axis, to meet the mirror at  $A$ ,  $B$ , etc. Join  $C$  to  $A$ . Since  $CA$  is a radius, it is perpendicular to the mirror at  $A$ , and is therefore the normal at  $A$ . Measure with a protractor the angle between this line and the ray incident at  $A$ , and mark off

an equal angle on the other side of the normal, giving the line  $AF$  for the direction of the reflected ray. Proceed similarly to draw the other reflected rays, which will be found to pass very nearly through a point on the principal axis midway between  $C$  and  $P$ .

If we take a concave mirror and stand fifteen feet or so from some brightly-lighted windows and then put a sheet of paper in front of and slightly to one side of the mirror, we can, by tilting the mirror and adjusting the distance of the paper, throw on to the paper a brilliant image of the windows. Let us see how this image is formed. First let us notice that when we look at a large distant object the rays we receive from a given point

on it (A, say, fig. 69) are nearly parallel to each other, although not parallel to the rays received from another point on the object, say B. Now, compared with the focal length of the mirrors we commonly use, fifteen feet is a considerable distance, and the rays of light from a point on the top of the window are practically parallel. Similarly, the rays from a point on the bottom of the window are also practically parallel although they make an angle with those from the top. These pencils of practically parallel light fall on the mirror, therefore, at slightly different angles to the principal axis, and so are brought to a focus at slightly different points the

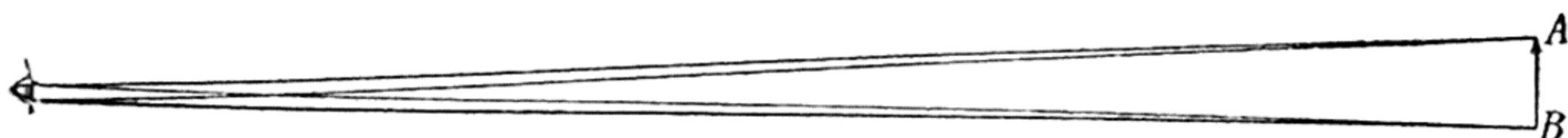


Fig. 69. — Rays of light from a distant object

same distance from the mirror, but at different distances from the principal axis. Actually, each point on the windows gives its own pencil of rays, which is focused by the mirror to give an image of that point, and the image of the windows is built up from all these point images. Observe that this image is *inverted*.

✓ Several points about such an image require to be noticed. The rays of light forming it do not merely appear to have come from the image, they actually pass through it. Such an image is called a **real image**. Real images are formed by converging pencils of light, and can be caught on a screen, whereas virtual images are formed by diverging pencils of light and cannot be caught on a screen. No one would dream, for example, of putting a sheet of paper behind a plane mirror and attempting to catch on it the virtual image of something in front of the mirror.

If we put a concave mirror close to our face we observe an erect magnified image of ourself, and this image is clearly behind the mirror. It must therefore

be virtual, because no rays of light can get behind the mirror. It is this image that we use when we employ a concave mirror as a shaving mirror. A concave mirror, then, can give us both real and virtual images. Let us see what are the conditions necessary to obtain each kind. We can find these out by tracing graphically the paths of rays after reflection.

In fig. 70 (a), let O be a point on the object, C the centre of curvature, F the principal focus, and P the pole of the mirror, all lengths being drawn to scale. Consider the ray OA parallel to the principal axis. We know that such a ray will pass after reflection through the principal focus. AF, therefore, is the path of the reflected ray. Draw the ray OCB through the centre of curvature. Since CB is a radius, this ray meets the mirror at right angles, and therefore is reflected straight back along its own path. The two reflected rays converge to the point I, which is therefore the image of O. In this way we could find the position of the images of each point on the object, but it will be sufficient for us to assume that, if the object is perpendicular to the principal axis, the image will be perpendicular to it also. We can therefore draw the image straight away. Two rays from O are sufficient to enable us to find the position of its image, but, had we required a third ray, we could have used the ray OF which, after reflection, proceeds parallel to the principal axis. In fig. 70 (a), the image is obviously real — the rays pass through it — and inverted. Also, it is smaller than the object. The ratio  $\frac{\text{length of image}}{\text{length of object}}$  is called the magnification, and in this case is less than 1. If we measure the distances of the image and object from the pole of the mirror, we shall find that:

$$\frac{\text{Length of image}}{\text{Length of object}} = \frac{\text{distance of image from mirror}}{\text{distance of object from mirror}}$$

In fig. 70 (b), the object is between the principal focus and the centre of curvature. The image is real,

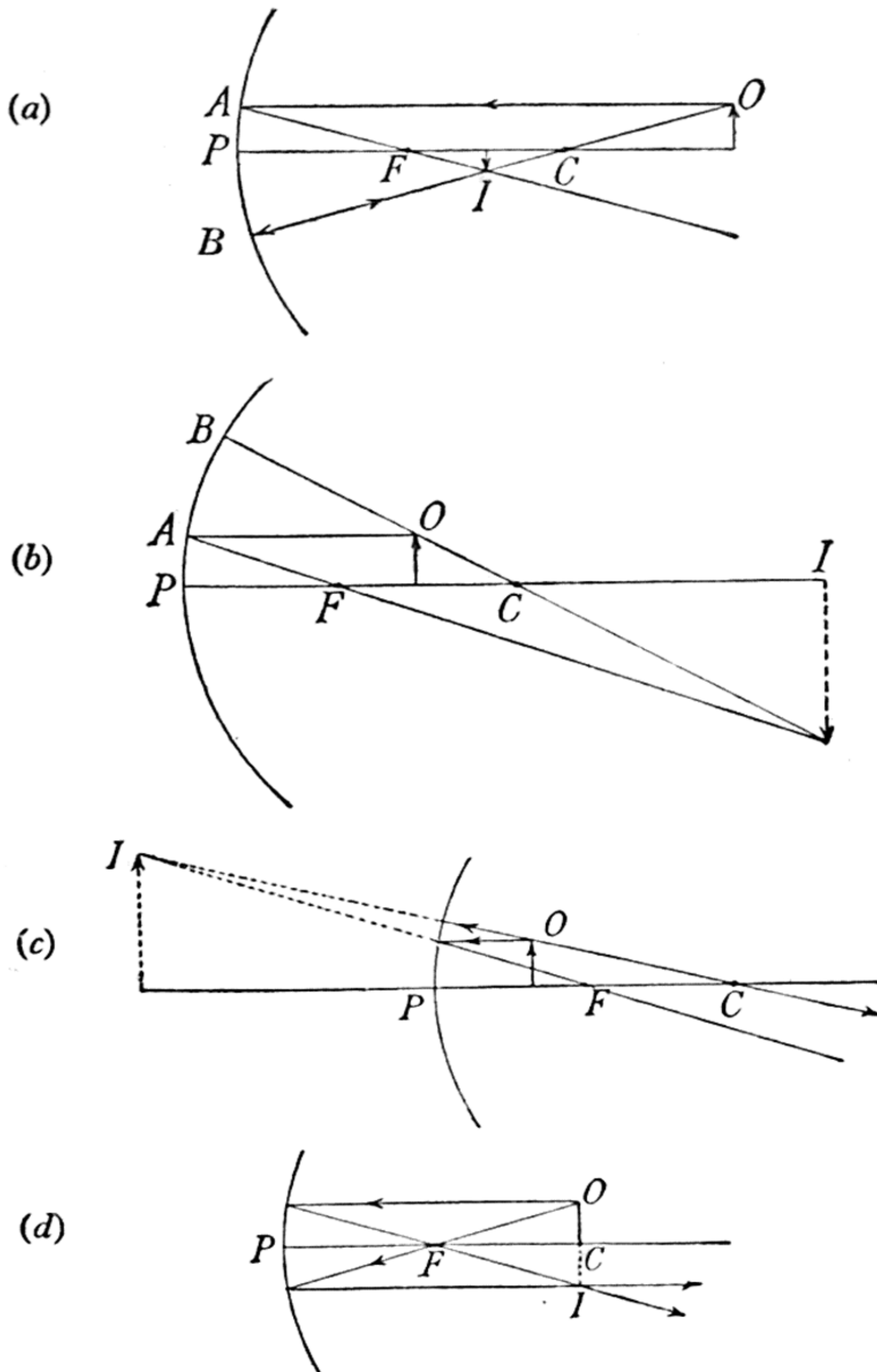


Fig. 70. — The formation of an image by a concave mirror

inverted, and larger than the object, i.e. the magnification is greater than 1. In fig. 70 (c), where the object is between the mirror and the principal focus, the image is behind the mirror, virtual, erect, and magnified.

To sum up:

1. When the object is beyond C, image is between F and C, real, inverted, and diminished.
2. When the object is between F and C, image is beyond C, real, inverted, and magnified.
3. When the object is between F and the mirror, image is behind the mirror, virtual, erect, and magnified.
4. When the object is at C, image is at C, real, inverted, and the same size as the object.

In the case of fig. 70 (*d*), where the object is at the centre of curvature, the construction ray through the centre of curvature fails, but we can still draw a figure by using the ray parallel to the principal axis and the ray through the principal focus.

**EXPERIMENT 15. — To find the focal length of a concave mirror.**

**(Method 1).** A cardboard screen *S* (fig. 71) has a circular hole in it across which pass two fine wires at right angles. An

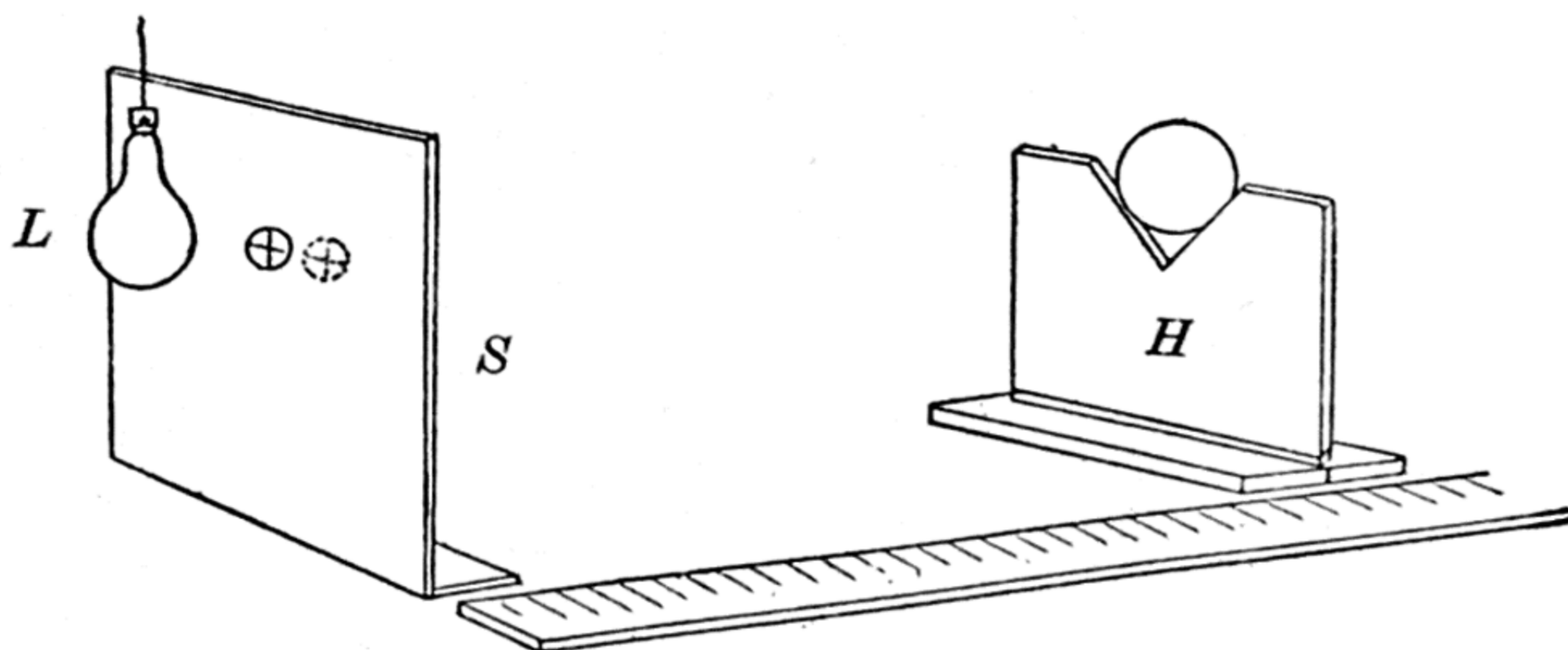


Fig. 71. — Simple optical bench for the determination of the focal length of a concave mirror

ordinary pearl electric lamp *L* is placed just behind the cross wires, causing the hole to be brightly illuminated. The mirror is placed in the holder *H*, the distance of which is adjusted until the real image of the cross wires formed by the mirror is

sharply focused on the screen beside the cross wires themselves. Image and object are now at the same distance from the mirror, and must therefore be at its centre of curvature. The distance of the screen from the mirror is measured with a metre rule. Dividing this distance by two we obtain the required focal length.

**(Method 2).** Stand as far from the windows as possible and throw their image on to a sheet of paper by means of the mirror. Measure the distance between the paper and the mirror. This is approximately the focal length of the mirror — approximately because the rays of light from the windows are not quite parallel. To obtain a more accurate value take a small triangular paper flag and place it, vertex outwards, in a clamp, in such a way that the flag is vertically over the mirror which rests on the bench. Tilt the paper so that the underside of the flag is illuminated by light from the windows. Adjust the position of the flag so that its height above the mirror is twice the approximate focal length already found. It will, therefore, be nearly at the centre of curvature of the mirror, and we shall obtain a real inverted image of its underside not far from the flag itself. This image can be seen by looking down from directly over the flag and mirror, keeping the eye at least a foot above the former. The beginner will find the image most easily if he first adjusts his position so as to see the reflection of his eye in the mirror, and then moves the object flag until it appears immediately over the image of his eye. The aim now is to adjust the flag at the centre of curvature of the mirror. Move the flag up and down until it appears the same size as the image. A final and more accurate adjustment can be made by the method of parallax (see Experiment 13). The position of the flag is adjusted until, after several trials, image and object no longer separate when the eye is moved sideways. The flag is now at the centre of curvature of the mirror, and its distance from the mirror is twice the required focal length.

## Convex Mirrors.

We have said very little so far about convex mirrors. These are less important than concave mirrors. If we look into a convex mirror, we see an erect, diminished image behind the mirror, irrespective of our distance from the mirror. We cannot get a real image with a

convex mirror. Fig. 72 shows the graphical determination of the position of the virtual image. The ray from  $O$ , parallel to the principal axis, proceeds after reflection

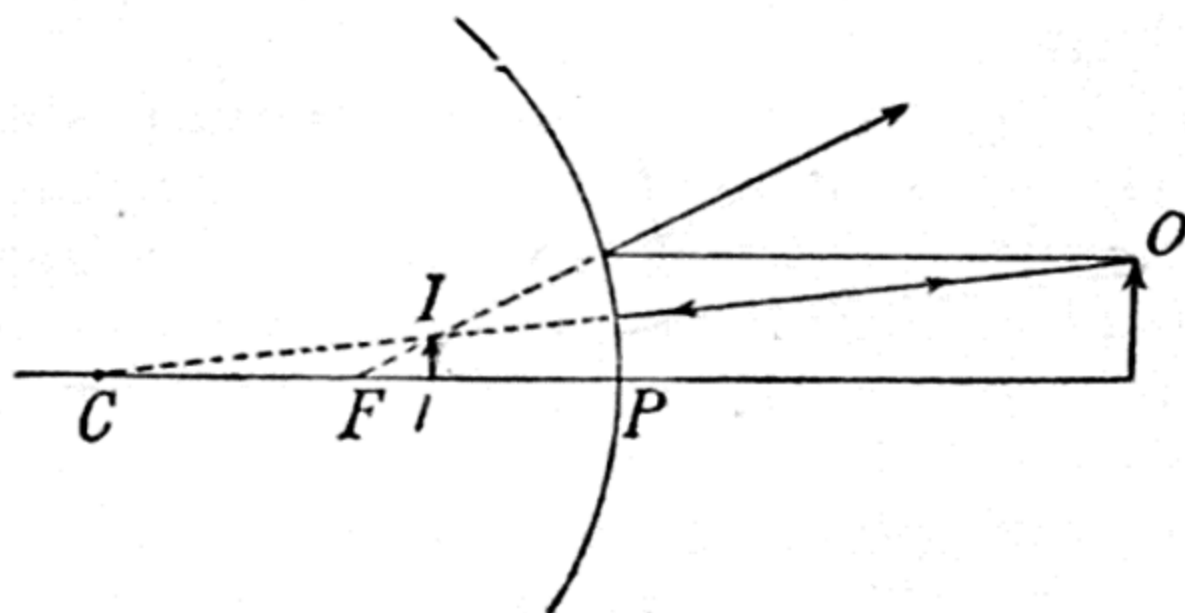


Fig. 72. — Formation of an image by a convex mirror

as though it had come from  $F$ , while the ray  $OC$ , which meets the mirror normally, is reflected back along its own path. The two reflected rays are diverging, and therefore cannot give a real image that could be thrown

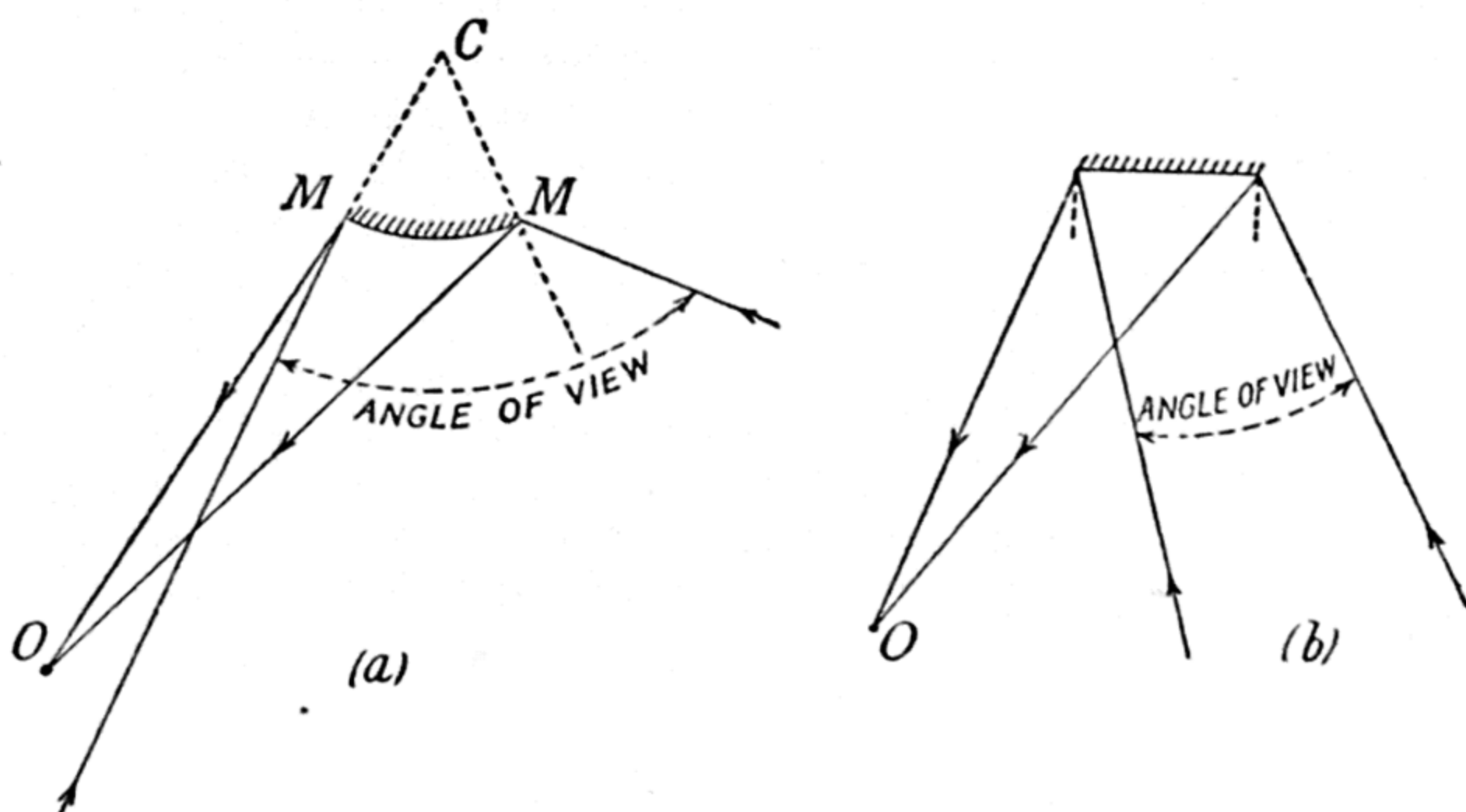


Fig. 73. — Field of view given by (a) a convex and (b) a plane mirror

on a screen, but the rays appear to have come from  $I$ , which is therefore the virtual image of  $O$ .  $I$  is always between  $P$  and  $F$ , whatever may be the position of  $O$ .

The driving mirrors of cars are usually convex

mirrors. They give an erect image, and since this is diminished they have a much larger field of view than a plane mirror (fig. 73).

The mirrors often seen at amusement fairs are not spherical, but cylindrical, that is, curved in one direction only like the curved surface of a cylinder. A mirror on the outside curved surface of a cylinder with its axis vertical acts as a convex mirror for horizontal lines, which are diminished in the image, and as a plane mirror for vertical lines, which appear in the image the same size as in the object.

The mirrors that we use in the laboratory are usually of small **aperture**, that is, they subtend only a small angle at their centre of curvature. We have seen that with these mirrors rays of light parallel to the principal axis are reflected so as to pass through a single point on the principal axis

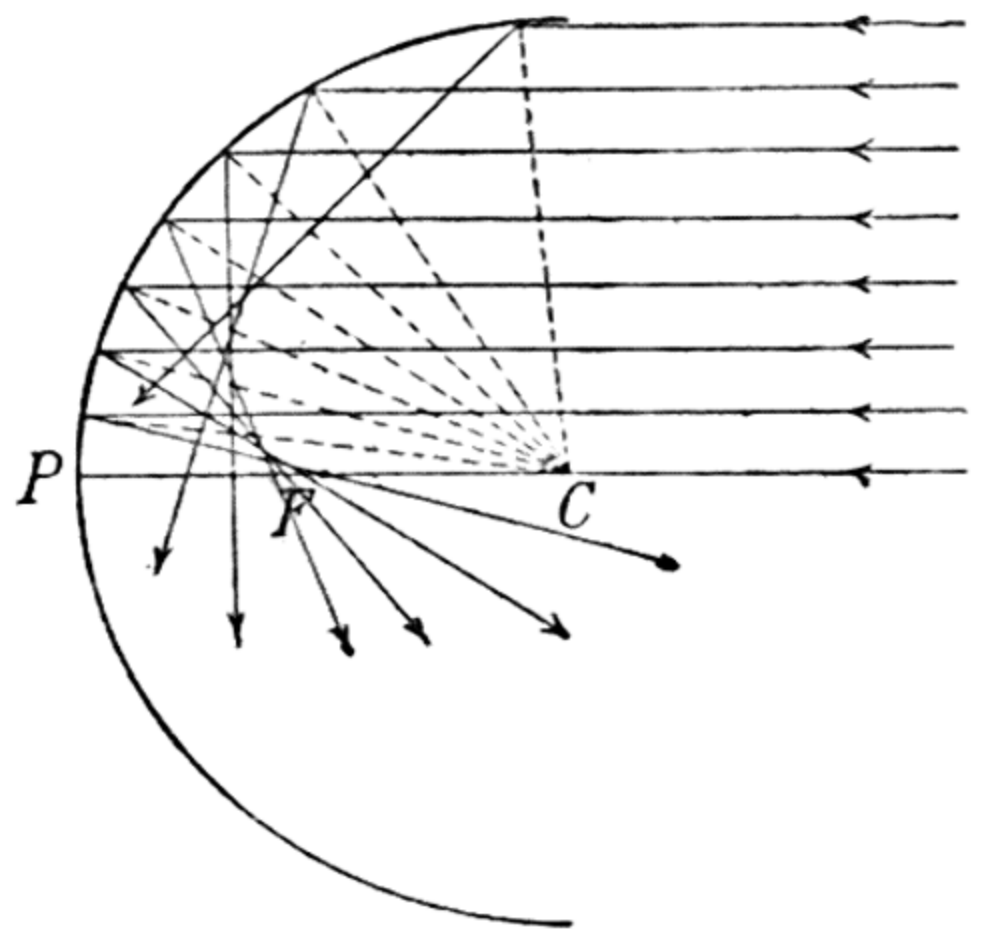


Fig. 74. — Spherical Aberration

that we call the principal focus. If we allow light to fall on a mirror of large aperture, we find that rays that strike the mirror some distance from the pole no longer pass through the principal focus. This failure of all the reflected rays to pass through the same point is called **spherical aberration**, and can be illustrated by using a semicircular cylindrical mirror (fig. 74).

The rays that strike the mirror near P pass through F. This can be shown by allowing the incident light to fall on the central portion of the mirror when a bright spot is visible at F. But the rays farther away from the pole do not pass through F, and the farther from the pole the ray strikes the mirror, the farther

from  $F$  the reflected ray crosses the principal axis. The consecutive reflected rays intersect each other along a curved line, called a **caustic** (fig. 75), which has a cusp at  $F$ , the principal focus. A caustic can often be seen in a cup of tea when a bright light falls on the inside of the cup.

It follows from this that if a bright source of light is placed at the principal focus of a concave mirror, those rays which strike the mirror near the pole will be re-

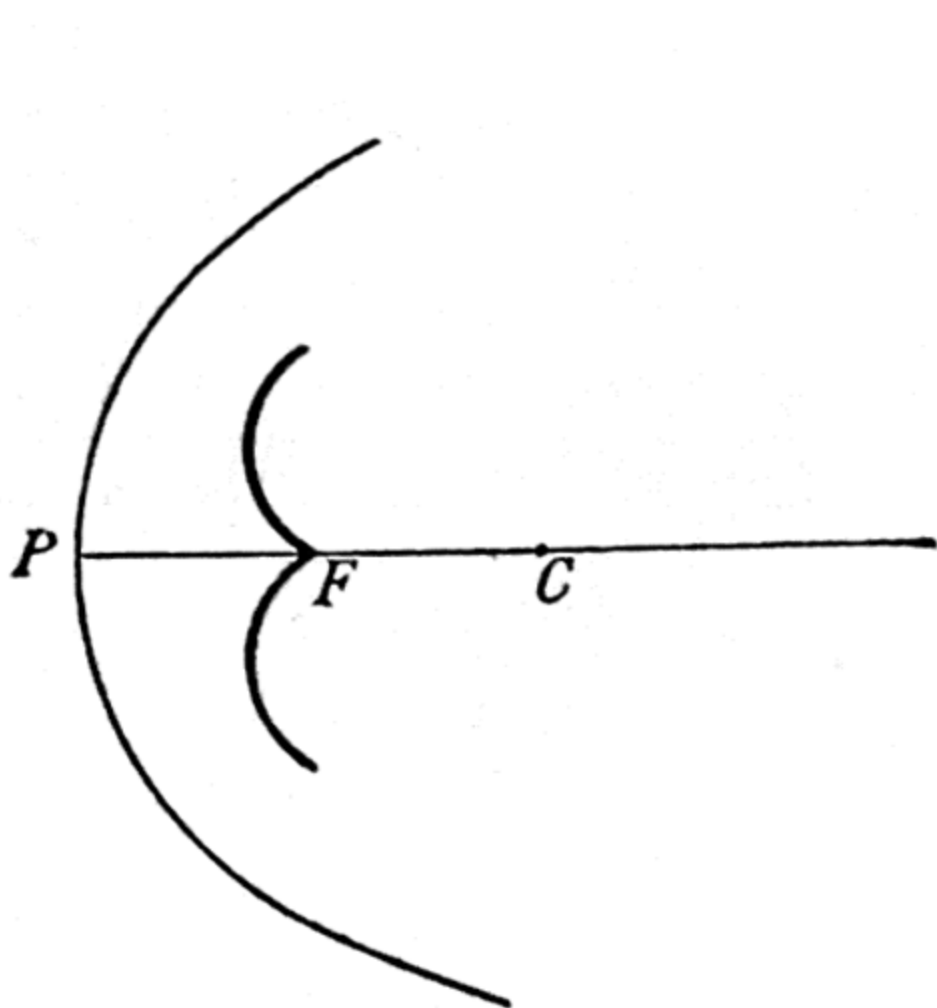


Fig. 75. — Caustic by reflection at wide-angle concave mirror

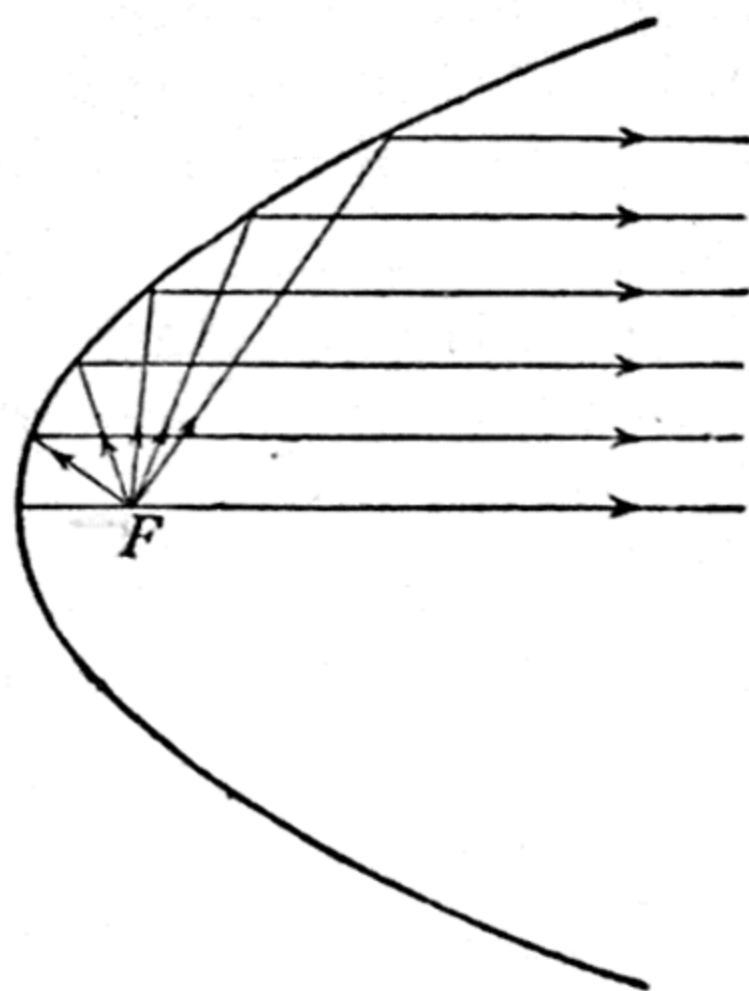


Fig. 76. — Reflection at a paraboloidal mirror

flected as a beam parallel to the principal axis, but the rays striking the mirror farther from the pole will not be reflected as part of this beam. Because of this, the reflectors fitted to the headlamps of cars are usually **paraboloidal** (fig. 76), for with this shape all rays from the focus are reflected parallel to the principal axis, no matter where they strike the mirror, and so a very powerful parallel beam is obtained. It is because the rays of light in such a beam do not spread out that the beam seems so powerful, although the lamps used in headlights are considerably less powerful than those employed for lighting an ordinary room.

QUESTIONS

1. Why do we believe that light travels in straight lines?
2. Explain the occurrence of (a) an eclipse of the sun, (b) an eclipse of the moon.
3. What do we mean by (a) a total eclipse, (b) a partial eclipse, (c) an annular eclipse?
4. A ray of light falls on a plane mirror at right angles. The mirror is rotated through an angle of  $30^\circ$ . What angle does the new direction of the reflected ray make with its original direction?
5. What do you understand by the term *image*? What are the properties of an image in a plane mirror? How would you show each of these properties?
6. Explain the terms *real image* and *virtual image*. How would you obtain each kind of image with a concave mirror?
7. What is *spherical aberration*? Describe an experiment to illustrate it.

## CHAPTER VI

### DENSITY AND FLOTATION

If you ask the average person why wood floats on water, while a metal, such as iron, sinks, he will probably tell you that it is "because wood is lighter and iron heavier than water". Although the point is not mentioned, it is quite clear that it is the weights of *equal volumes* that are to be compared. The ratio of the weight of a body to the weight of an equal volume of water is called its specific gravity. The specific gravity of water is obviously 1. Note that specific gravity is what is called a "pure number", because it does not need any unit after it; it is merely **how many times** heavier the substance is than an equal volume of water, and is the same whether we are weighing in pounds or in grams.

In scientific work it is more usual to speak of the **density** of a substance. The density of a body is the mass of unit volume of it, i.e. of 1 c.c., or of 1 cubic foot, as the case may be. When we are writing down the density of a body it is necessary to mention the units both of mass and of volume. Thus the density of water is 1 gram per cubic centimetre (1 gm./c.c.), on the C.G.S. (Centimetre-Gram-Second) system, or 62.5 pounds per cubic foot (62.5 lb./cu. ft.), on the F.P.S. (Foot-Pound-Second) system. This does not mean that water has two different densities, one when it is measured in grams per c.c., and the other when it is measured in

pounds per cubic feet. It is the same density but expressed in different ways, just as "60 miles per hour" and "88 feet per second" represent exactly the same speed, but in different units.

If a metal has a density of 8.0 gm./c.c., its specific gravity is

$$\frac{\text{weight of 1 c.c. of metal}}{\text{weight of equal volume of water}} = \frac{8 \text{ gm.}}{1 \text{ gm.}} = 8.$$

That is to say, specific gravity is expressed by the same *number* as the density on the C.G.S. system — but when we are referring to the density we must add "gm./c.c." after the number. Since 1 cu. ft. of water weighs 62.5 lb., the density of the metal on the F.P.S. system, i.e. the mass of 1 cu. ft. =  $8 \times 62.5 \text{ lb./cu. ft.} = 500 \text{ lb./cu. ft.}$  That is, the density of a substance on the F.P.S. system and its specific gravity are not represented by the same number.

✓ **EXPERIMENT 16. — To find the density of a regular solid.** Take a cube or rectangular block of wood or metal and weigh it. Find the length of its side by measuring with a rule (in centimetres). Calculate the volume of the solid. Suppose that

	Mass of solid	= 6.0 gm.
	Volume of solid	= 8.0 c.c.
Then	Density of solid = $\frac{\text{mass}}{\text{volume}}$	= $\frac{6.0 \text{ gm.}}{8.0 \text{ c.c.}}$
		= 0.75 gm./c.c.

If from the measurements of the preceding experiment we had wished to find the specific gravity of the substance, we should have proceeded as follows:

Mass of solid	= 6.0 gm.
Volume of solid	= 8.0 c.c.
Weight of equal volume of water	= 8.0 gm.,
(because 1 c.c. of water weighs 1 gm.)	

Therefore, specific gravity of solid

$$\begin{aligned}
 &= \frac{\text{weight of solid}}{\text{weight of equal volume of water}} \\
 &= \frac{6.0 \text{ gm.}}{8.0 \text{ gm.}} \\
 &= 0.75.
 \end{aligned}$$

**EXPERIMENT 17. — To find the specific gravity of brine.** For this experiment we use an apparatus called a specific gravity bottle, or density bottle (fig. 77). This consists of a



Fig. 77. — Specific Gravity Bottle or Density Bottle.

glass bottle with a ground glass stopper slightly tapering in shape so that it will fit well. The stopper has a fine hole running the whole of its length. Weigh the bottle empty. Then fill it with brine and put the stopper in. Some of the brine will come out through the hole in the stopper. Wipe the bottle dry on the outside and weigh it again. Hold the bottle by the neck, otherwise the warmth of your hand will cause the liquid in the bottle to expand and some of it will come out. Empty out the brine, rinse out the bottle with water, and then fill it with water. Put the stopper in, wipe the bottle dry, and weigh it. The bottle holds equal volumes of brine and of water, and the specific gravity of the

brine will therefore be the ratio of the weights of the liquids contained. Let

Weight of bottle empty	= 20 gm.
Weight of bottle full of brine	= 73 gm.
Weight of bottle full of water	= 70 gm.
Weight of brine filling bottle	= 53 gm.
Weight of water filling bottle	= 50 gm.

$$\therefore \text{specific gravity of brine} = \frac{53 \text{ gm.}}{50 \text{ gm.}} = 1.06.$$

To find the density of brine notice that, since the bottle holds 50 gm. of water, it must hold 50 c.c. of water, and therefore 50 c.c. of brine. That is, 53 gm. of brine occupy 50 c.c. Therefore the density of brine

$$= \frac{53 \text{ gm.}}{50 \text{ c.c.}} = 1.06 \text{ gm./c.c.}$$

**EXPERIMENT 18.** — Find the specific gravity of a block of natural rubber or of teak by the method of Experiment 16, and of methylated spirits by that of Experiment 17. Find out whether the rubber floats in (a) water, and (b) methylated spirits. What conclusion can you draw as to the condition that a solid will float in a given liquid?

We have seen that a substance floats in a liquid if it has a lower specific gravity than the liquid. We can carry the question a stage farther — *why* does such a solid float? The reason is that liquids exert an upward force on substances immersed in them. If the liquid has a specific gravity greater than that of the solid immersed in it, this force is sufficiently great to counter-balance the whole of the weight of the solid. It is easy enough to see that such a force exists. If you dip your fingers into mercury, it is very obvious that there is an upward force on them due to the liquid, and as you sit in a bath your legs tend to rise to the surface of the water. An upward force is exerted also on a body that sinks in a liquid, although in this case the force is insufficient to balance the weight of the body.

**EXPERIMENT 19.** — To show that there is an upward force exerted on a body immersed in water. Suspend a brick from the hook of a spring balance and observe the reading of the balance. Gradually immerse the brick in a bucket of water (fig. 78). Note that as the brick is gradually immersed the reading of the spring balance gradually decreases. When the brick is wholly immersed its apparent weight is much less than its weight in air and does not change if the brick is held at varying depths below the surface, so long as it is wholly immersed. Since the apparent weight of the brick is

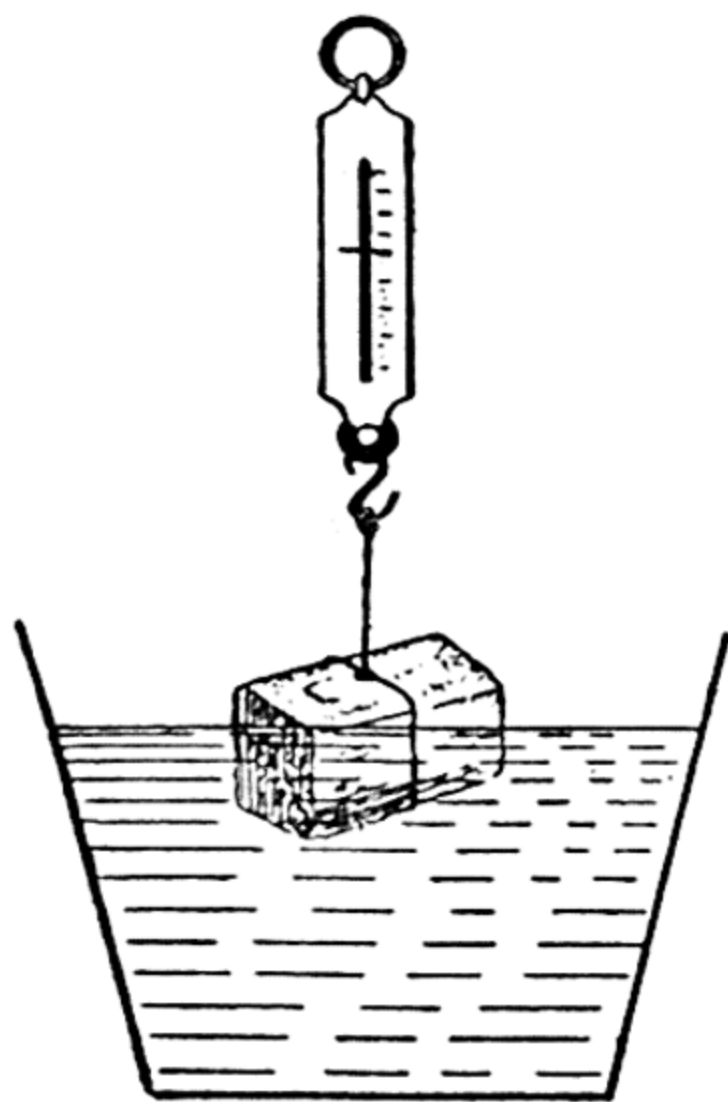


Fig. 78. — Weighing a Brick immersed in Water.

less when it is immersed in water it follows that there must be an upward force exerted on the brick, due to the "buoyancy" of the water.

### **Archimedes' Principle.**

A connection between the apparent loss of weight and the volume of the body immersed was discovered more than 2000 years ago by Archimedes, one of the greatest scientists of all time. Archimedes lived at Syracuse, a very important seaport in Sicily, and studied, probably under Euclid, at the great University at Alexandria. Archimedes was asked by Hieron, King of Syracuse, to find out whether a gold crown the latter had had made consisted of pure gold or whether the gold had been alloyed with silver. Archimedes was not, however, to damage the crown. The story goes that as Archimedes was in his bath he noticed how some of the water overflowed as he stepped into it, and suddenly saw how to solve the problem of the crown. He was so excited that he ran home naked through the streets shouting "*Eureka*" ("I have found it"). Archimedes realized that when a body is immersed it displaces a volume of liquid equal to its own. Gold has a greater density than silver, while an alloy of the two would be intermediate in density. If equal weights of gold, silver, and alloy were taken, the volume of the alloy would be less than that of the silver but greater than that of the gold. All that remained was for Archimedes to find whether the crown displaced a greater volume of water than an equal weight of pure gold. According to the story, Archimedes found that some of the gold had been replaced by silver, but the fate of the goldsmith is not on record.

When equal weights of gold and silver were weighed in water, Archimedes found that the apparent loss of weight of the silver was greater than that of the gold — and the silver displaced a greater volume of water.

Archimedes soon found the connection between the apparent loss in weight of a body immersed in water and the volume of the body, and was able to state the celebrated rule still known as **Archimedes' Principle**:

**When a body is wholly or partly immersed in a liquid there is an upward thrust on the body equal to the weight of liquid displaced.** ✓

✓ **EXPERIMENT 20. — To verify Archimedes' Principle (fig. 79).**

**(Method 1).** Suspend half a brick from the hook of a spring balance and note its weight in air. Fill a "Eureka can" with water until it overflows, and when it has stopped dripping place under the spout a large beaker that has been weighed on a pair of scales. Immerse the brick in the can. Note the new reading of the spring balance, and when the can has stopped dripping weigh the beaker again. The difference between the initial and final readings of the spring balance gives the apparent loss of weight in water, and the increase in weight of the beaker gives the weight of water displaced.

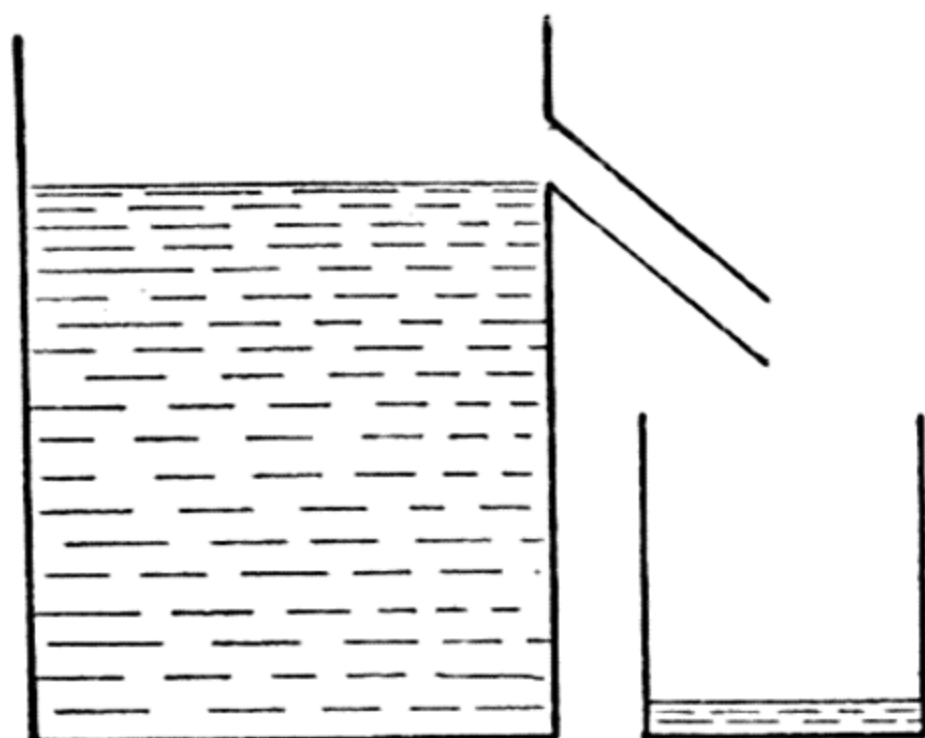


Fig. 79. — Eureka Can and Beaker to receive Overflow

✓ **(Method 2).** Suspend a metal cylinder from the hook of a chemical balance by a piece of thread and weigh it. Put a wooden bridge over the left-hand balance pan, and on the bridge put a beaker containing water (fig. 80). The weight of the beaker and water is carried by the bridge and does not affect the balance. Suspend the metal cylinder so that it is completely immersed in the water, and weigh it again. There will appear to be a considerable loss in weight due to the upward force exerted by the buoyancy of the water. Measure the cylinder and calculate its volume. It displaces its own volume of water and, since 1 c.c. of water weighs 1 gm., the weight of water displaced by the cylinder can thus be found. Compare this with the observed loss in weight of the cylinder on immersion in water. If this is done as a class experiment,

different groups taking solids of different densities, the demonstration of the Principle is even clearer.

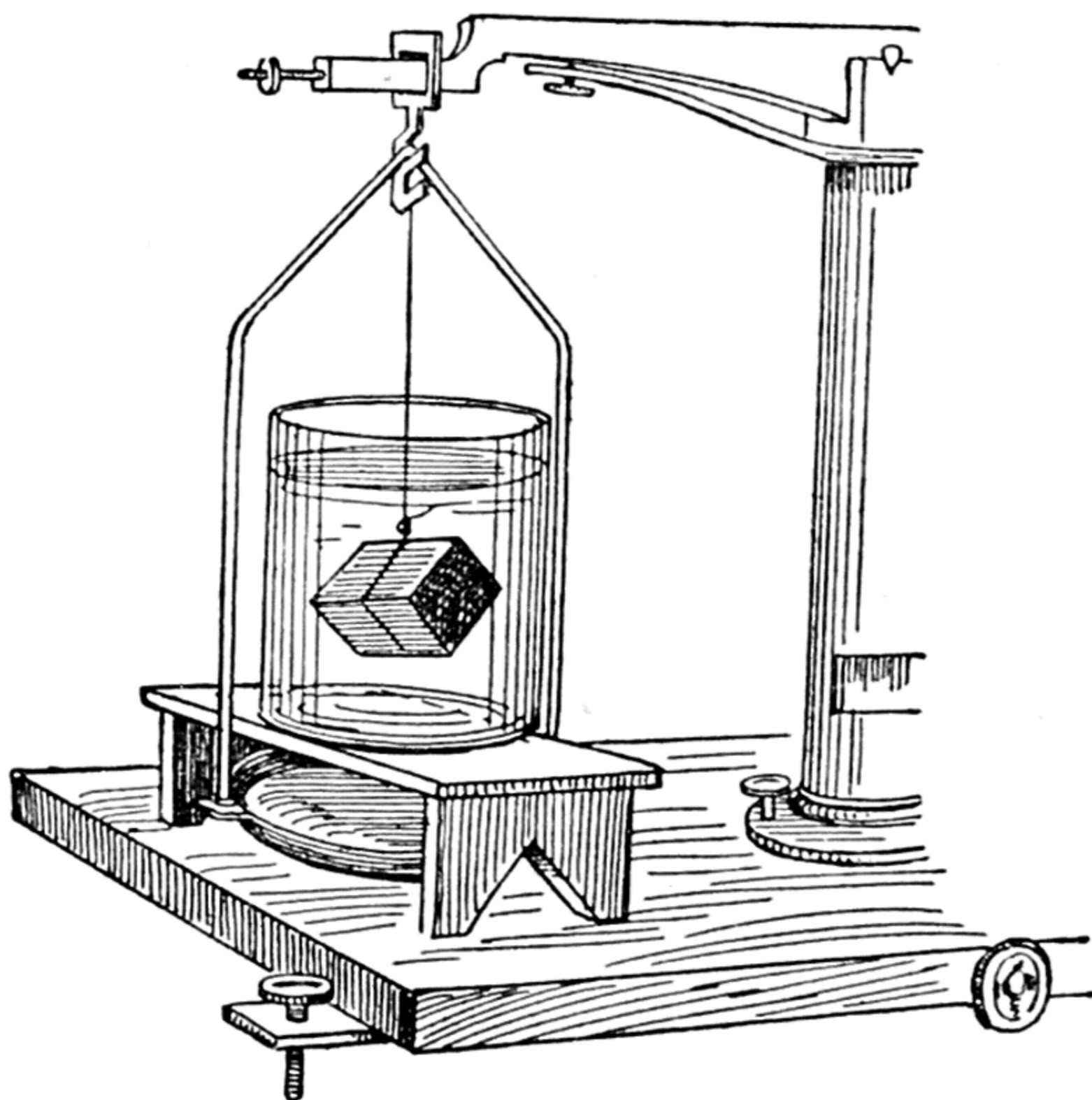


Fig. 80. — Weighing a solid immersed in water, using a chemical balance

**EXPERIMENT 21. — To find the density of an irregular solid by Archimedes' Principle.** Weigh a glass stopper in air and then in water, as in Experiment 20 (Method 2). Let

Weight of stopper in air = 50 gm.

Weight of stopper in water = 30 gm.

∴ Apparent loss of weight in water = 20 gm.

∴ by Archimedes' Principle, weight of water displaced = 20 gm.

But 1 gm. of water occupies 1 c.c.

∴ Volume of solid = volume of water displaced = 20 c.c.

∴ Density of glass stopper =  $\frac{50 \text{ gm.}}{20 \text{ c.c.}} = 2.5 \text{ gm./c.c.}$

**EXPERIMENT 22. — To find the density of a liquid by Archimedes' Principle.** Weigh a suitable solid, e.g. a glass stopper, in air, water, and the liquid whose density is to be found. Let

Weight of stopper in air = 50 gm.

Weight of stopper in water = 30 gm.

Weight of stopper in methylated spirits = 34 gm.

Then, as in Experiment 21 above, volume of glass stopper = 20 c.c.

Now, apparent loss of weight of stopper in methylated spirits = 16 gm.

∴ by Archimedes' Principle, weight of methylated spirits displaced = 16 gm.

But volume of methylated spirits displaced = volume of the glass stopper = 20 c.c.

∴ Density of methylated spirits

$$= \frac{16 \text{ gm.}}{20 \text{ c.c.}} = 0.8 \text{ gm./c.c.}$$

## Hydrometers.

The density of milk is slightly greater than that of water, so that its density is lowered if water is added to it. A determination of the density of a sample of milk can therefore be used to detect the addition of water. As an accumulator runs down, the density of the acid in it gradually decreases, so that we can find out whether it requires recharging by measuring the density of the acid. For these and other purposes it is often necessary to find the density of a liquid. A very quick and convenient method in such cases is to use an instrument called a hydrometer, a common form of which is shown in fig. 81. It consists of a sealed hollow glass tube, weighted at the bottom with mercury, so that it will

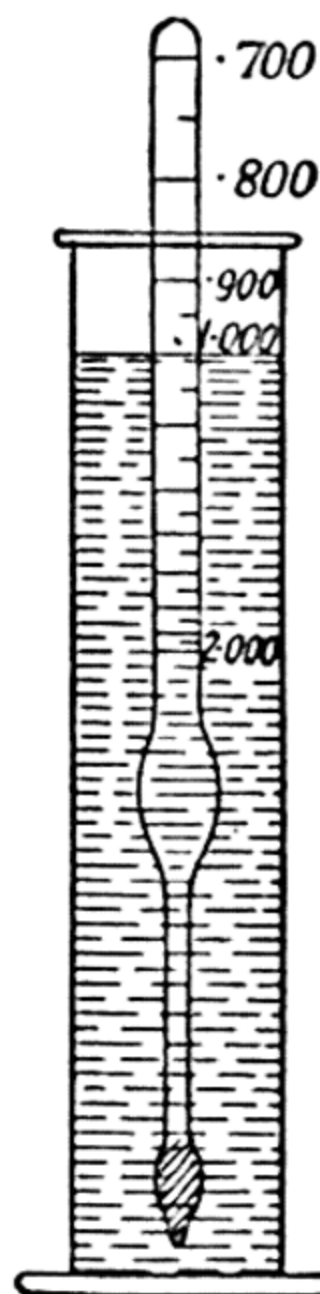


Fig. 81. — Hydrometer

float in an upright position. The top part of the stem is narrow and carries a paper scale inside it. When the instrument is placed in the liquid it sinks to such a level that it displaces its own weight of liquid. The smaller the density of the liquid the greater the volume of liquid that will be displaced. Thus, if the hydrometer weighs 100 gm., it will displace 100 c.c. of water, but  $100/0.8$ , or 125, c.c. of methylated spirits (density 0.8 gm./c.c.). That is, less of the stem will be above the surface of the liquid if the hydrometer is in methylated spirits than if it is in water. The stem is graduated in such a way that the scale reading level with the surface of the liquid gives the specific gravity of the latter directly. It should be noted that the marks on the scale are not evenly spaced. If we wished to use such an instrument to read over a wide range of densities, either we should have to use a hydrometer with a broad stem, in which case the scale marks would be close together so that we should not be able to read the instrument very accurately, or else we should have to use a very long stem. To overcome this

#### DENSITIES OF COMMON SUBSTANCES (in gm./c.c.)

Aluminium	..	..	2.7	Milk	..	..	..	1.03
Ash (wood)	..	..	0.6–0.8	Nickel	..	..	..	8.9
Coal	..	..	1.2–1.5	Oak	..	..	..	0.7–0.9
Copper	..	..	..	Petrol	..	..	..	0.68–0.72
Cork	..	..	0.22–0.26	Pine (white)	..	..	..	0.4–0.5
Ebony	..	..	1.1–1.3	Platinum	..	..	..	21.5
Glass (crown)	..	..	2.4–2.6	Potassium	..	..	..	0.86
Glycerin	..	..	1.26	Rubber (natural)	..	..	..	0.91–0.93
Gold	..	..	19.3	Sand	..	..	..	2.63
Ice	..	..	0.92	Sea-water	..	..	..	1.01–1.05
Iodine	..	..	5.0	Silver	..	..	..	10.5
Iron	..	..	7.9	Sodium	..	..	..	0.97
Lead	..	..	11.4	Sulphur (rhombic)	..	..	..	2.1
Magnesium	..	..	1.7	Tin	..	..	..	7.3
Marble	..	..	2.5–2.8	Turpentine	..	..	..	0.87
Mercury	..	..	13.6	Zinc	..	..	..	7.1
Methylated spirits	..	..	0.83					

difficulty a given hydrometer is constructed to read over only a small range of densities, and if widely varying densities are to be measured a set of hydrometers is employed, each reading over only a portion of the total range. When employed to measure the density or specific gravity of milk the instrument is usually referred to as a **lactometer**.

A simple hydrometer can be made by putting some lead shot in the bottom of a test-tube and corking the tube. Why would such an instrument not be very suitable for accurate work?

### How Ships Float.

When it was first suggested that ships should be built of iron instead of wood, many people said that the idea was absurd because, since iron was heavier than water, the boats would go straight to the bottom. As we know, this is not so, and nowadays all large ships are made of steel. Why do they float? Because they can displace a weight of water equal to their own weight. They are able to do this because of their shape, which enables them to displace a volume of water very much greater than the volume of metal used in their construction.

The weight of water displaced by a ship when it floats is equal to the total weight of the ship and its contents. When a ship is loaded with cargo, the total weight increases, and so the boat sinks lower in the water. Sea-water has a density of about 1.025 gm./c.c., varying a little with locality and season of the year. Fresh water has a density of 1.0 gm./c.c., so that a given vessel has to displace a greater volume of fresh water than of salt water in order to displace its own weight of liquid. It is obviously undesirable to overload a boat, as it is then unable to withstand bad weather so easily. The depth to which British vessels may be loaded under varying conditions is prescribed by Board

of Trade Regulations, and the appropriate levels are marked on the side of the ship. This is the **Plimsoll**

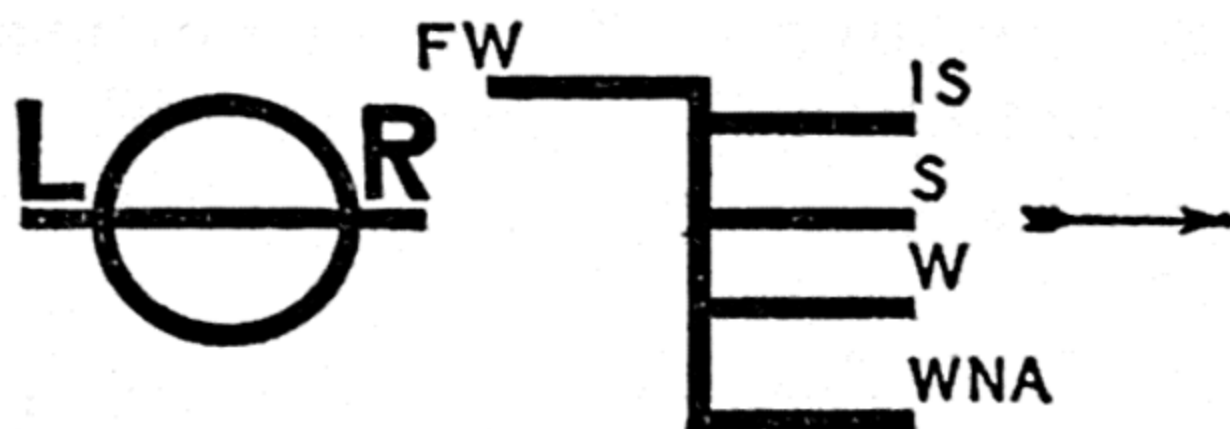


Fig. 82. — Plimsoll Line

LR, Lloyd's Register of Shipping. FW, Fresh water. IS, Indian Summer. S, Summer. W, Winter. WNA, Winter North Atlantic.

**Line**, named after Samuel Plimsoll (1824–98), who devoted much time and energy to securing this safeguard for sailors.

### The Submarine.

Inside a submarine there are a number of ballast tanks. When these tanks contain air the vessel is lighter than its own volume of water, and so floats on the surface. When the vessel is about to submerge, water is admitted to the tanks through valves until the weight of the vessel and contents is slightly greater than that of its own volume of water. The submarine then starts to sink. Since it is now "heavier than water" it would continue to sink were it not for the force exerted by the water on the almost horizontal fins, or **hydroplanes**, when the boat moves forward under the power of its engines. The submarine can be "trimmed" or kept at a constant depth by adjusting the angle of the hydroplanes. In order to return to the surface, water in the ballast tanks is pumped out by means of compressed air, whereupon the vessel once more becomes lighter than its own volume of water.

## The Density of Gases.

So far we have considered only bodies floating in liquids. Air, also, has weight and exerts an upward force on bodies immersed in it, equal to the weight of the air displaced. In stating Archimedes' Principle we should really use the term "fluid" (which includes both liquids and gases) rather than the term "liquid".

**EXPERIMENT 23. — To show that air has weight.** Take a dry flask of about 500 c.c. capacity and fit it with a rubber cork through which passes a piece of glass tubing attached to a short length of pressure tubing (thick-walled rubber tubing), carrying a screw clip (fig. 83). It is as well to seal the cork by running a little molten paraffin-wax round the rim of the neck of the flask and allowing it to set. With the clip open, attach the pressure tubing to a good filter pump for two or three minutes. The filter pump will remove the air from the flask. With the pump still working, screw up the clip tightly, then remove from the pump and weigh the apparatus. Open the clip and note the hissing sound as air rushes into the flask. Weigh the apparatus again. Now find by means of a measuring cylinder the volume of water required to fill the flask up to the cork. We should obtain some such results as the following:

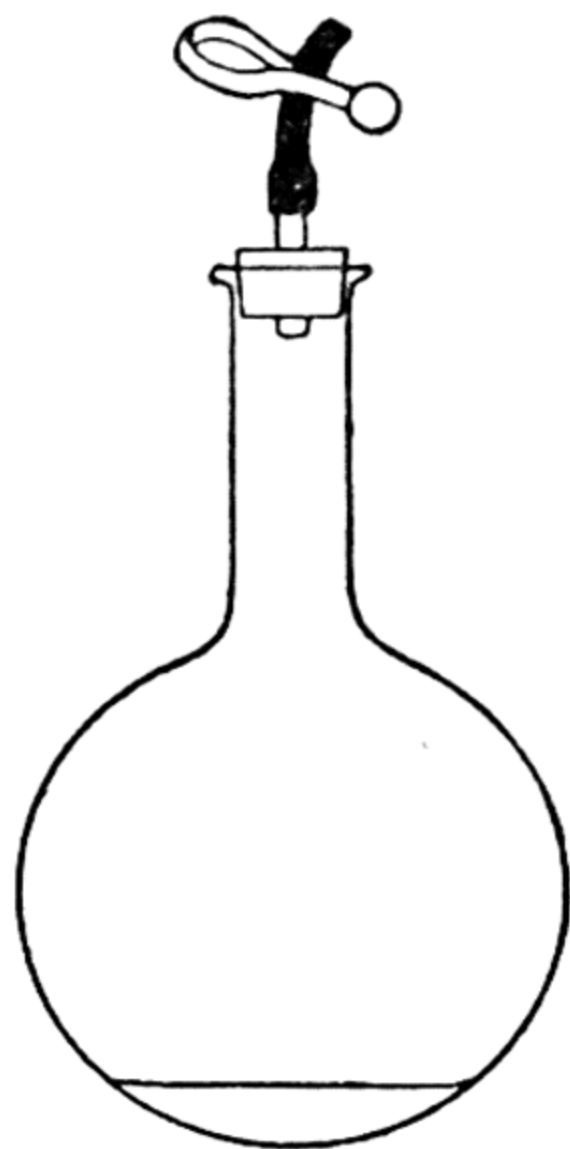


Fig. 83. — To show that air has weight

Weight of apparatus exhausted of air	= 150.0 gm.
Weight of apparatus full of air	= 150.6 gm.
Volume of water required to fill flask	= 550 c.c.
Weight of air filling flask	= 0.6 gm.

$$\therefore \text{density of air} = \frac{0.6 \text{ gm.}}{550 \text{ c.c.}} = 0.0011 \text{ gm./c.c.} \\ = 1.1 \text{ gm./litre.}$$

(A more accurate value for the density of air is 0.00128 gm./c.c., which is equivalent to 0.081 lb./cu. ft.)

It will help us to get a better idea of the weight of air if we realize that the total weight of the air filling the average school laboratory is about  $\frac{1}{4}$  ton. A body will float in air if its weight is less than that of its own volume of air. A balloon consists of a basket attached to a gas bag which can be inflated with a very light gas called hydrogen (see p. 238). Hydrogen has a density only  $\frac{1}{14}$  that of air. Let us calculate the lifting power of an imaginary balloon, remembering that the weight of 1 cu. ft. of hydrogen is 0.0056 lb. Let

Volume of inflated gas bag and basket	=	15,000 cu. ft.
Weight of gas bag	=	200 lb.
Weight of basket	=	32 lb.

Neglecting the volume of the basket, we may say that the volume of hydrogen in the gas bag is 15,000 cu. ft. and its weight therefore is  $0.0056 \times 15,000 = 84$  lb.

$$\begin{aligned} \text{Total weight of balloon and contents} \\ = 200 + 32 + 84 = 316 \text{ lb.} \end{aligned}$$

$$\begin{aligned} \text{Weight of air displaced} \\ = 15,000 \times 0.081 = 1215 \text{ lb.} \end{aligned}$$

By Archimedes' Principle, therefore, the upward thrust on the balloon is greater than its weight by  $1215 - 316 = 899$  lb.

A balloon will not go on rising indefinitely because, as the altitude increases, the density of the air becomes less, and a balloon ceases to rise when its average density becomes the same as that of the surrounding air. If ballast, such as sand, has been taken up, the balloon can be caused to rise higher by dropping the sand overboard. On opening a valve and allowing some of the gas to escape, the volume of the balloon is diminished and, since its weight remains practically the same, its density increases, and so it begins to descend.

The great drawback to using hydrogen in a balloon

or airship is that the gas is very inflammable, and several terrible disasters have occurred owing to airships catching fire. This danger can be avoided by using another light gas called **helium**, but unfortunately the supply of this gas is very limited. Although a given volume of helium is twice as heavy as an equal volume of hydrogen, the lifting power of a balloon filled with helium is not much less than that of a hydrogen balloon of the same size. Using the example we took above, we should require 168 lb. of helium to fill the gas bag, instead of 84 lb. of hydrogen. The lifting power of the balloon would therefore be reduced by 84 lb., i.e., from 899 lb. to 815 lb., or about  $\frac{1}{11}$ .

It may be noted here that the term "density", when used in connection with a gas, usually means its specific gravity referred to hydrogen, the lightest of all known substances. That is, helium would be said to have a density of 2.,

### QUESTIONS

1. If 36 gm. of a liquid of density 1.8 gm./c.c. are mixed with 30 gm. of water (density 1.0 gm./c.c.) and no change in volume occurs, what will be the density of the mixture? What would it be if there were a diminution in volume of 5 c.c. on mixing?

2. Ice has a density of 0.91 gm./c.c. Explain why an iceberg floats with only about  $\frac{1}{9}$  of its volume above water.

3. A density bottle weighs 20 gm. empty, 70 gm. full of water, and 700 gm. full of mercury. Find the density of mercury.

4. Why does a diver have heavy weights on the feet of his diving suit?

5. What weight can be lifted by (a) 1 litre of hydrogen, density 0.089 gm./litre, (b) 1 litre of coal-gas, density 0.75 gm./litre? The density of air is 1.28 gm./litre.

6. How would you verify Archimedes' Principle experimentally?

7. A corked test-tube containing lead shot weighs 32 gm. and floats vertically with  $\frac{1}{3}$  of its length above water. What is its volume? What proportion of the test-tube would float above the surface of alcohol (density 0.8 gm./c.c.)?

8. The closed end of a test-tube is flattened and the tube weighted with lead shot so that it floats upright in water. If 10 cm. of the tube are immersed when the tube floats in distilled water, how far will it sink in a liquid of specific gravity 0.8? If the mass of the weighted tube is 31 gm., what is the diameter of the test-tube? ( $\pi = 3.14$ .) Explain each step in your calculations. L.

9. Suppose two new gases were discovered, one being inflammable and having a density  $\frac{1}{10}$  that of hydrogen, the other non-inflammable with the same density as hydrogen. Discuss their relative usefulness in balloons. L. (part)

10. What do you understand by the expression "the density of a solid"? A block of insoluble substance, whose volume is 40 c.c., weighs 36 gm.; will the body float or sink in water? Give reasons for your answer and state the principle involved.

11. State and explain what happens to a laden ship as it sails from the open sea up one of the great navigable rivers. C.W.B. (part)

12. State the Principle of Archimedes, and describe how you would verify it by experiment. A hollow stopper, made of glass of specific gravity 2.5, weighs 40 gm. in air, but appears to weigh only 17 gm. when totally immersed in water. What is the volume occupied by the cavity in the stopper? C.W.B.

13. A piece of iron sinks in water yet an iron ship floats. Explain this. What volume of lead, of density 11.5 gm./c.c., must be attached to a block of wood of volume 500 c.c. and density 0.5 gm./c.c. so that the combination may just sink in water? C.W.B.

14. A rod of wood of rectangular cross-section weighted at one end has a relative density of 0.7 gm./c.c. It is 3 cm. by 2 cm. in cross-section and 15 cm. long. Find (a) the volume of water it will displace when floating in water, (b) the weight of the wood, (c) the weight which, if placed on top, would just cause total immersion of the rod, (d) the volume of the wood below the surface when the rod is floating in methylated spirits whose relative density is 0.8. C.W.B.

## CHAPTER VII

### ✓ FLUID PRESSURE

If we consider a pile of books resting on a table, it is clear that the books must exert a downward force on the table equal to their weight. This force is spread uniformly over the whole of the area on which the books rest. Let us suppose the books weigh 10 lb., and that they rest on an area of 40 sq. in. Then the force acting downwards on each sq. in. of table is  $\frac{1}{4}$  lb. We say that the weight of the books exerts a **pressure** on the surface. The magnitude of a pressure is defined as the force acting on unit area, so in the above case it would be  $\frac{1}{4}$  lb. per square inch. The total force acting on the surface is called the **thrust**. In the same way if we had 10 lb. of water in a rectangular vessel with a base whose area is 40 sq. in., then here again the weight of the liquid would exert a pressure on the base of the vessel equal to  $\frac{1}{4}$  lb. per square inch. There is, however, an important difference between the two cases. A liquid differs from a solid in having no definite shape of its own, and in taking the shape of the vessel containing it. If we were to bore two or three small holes in the side of the vessel, the liquid would pour out, moving in a horizontal direction as it left the vessel, and we should notice further that the force of the jet was greater the lower the opening (fig. 84). It is clear, therefore, that a liquid (and, as we shall see later, a gas also) exerts a pressure not only on the base of the containing vessel, but also on its sides, the pressure being in each case at right angles to the surface on which it

is acting. We have already seen in the previous chapter that a liquid exerts an upward thrust on a body immersed in it.

If we double the height of the liquid column, we should double the pressure on the base, since we have double the original weight, and this would still be spread over the same area. That is, liquid pressure depends on the height of the liquid column. We often speak of the height of a liquid column as its "head".

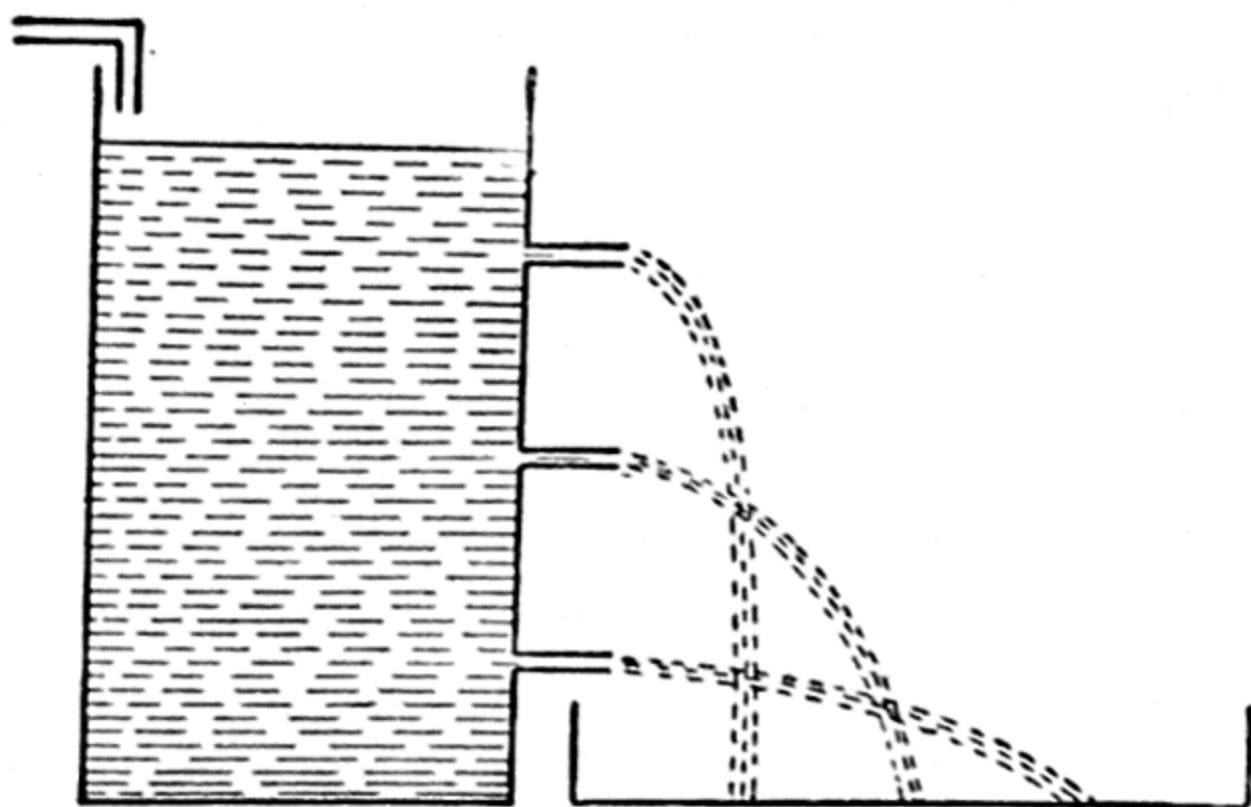


Fig. 84. — To show that pressure in a liquid varies with depth

If, instead of having, say, a foot of water in the vessel, we had a foot of mercury, it is clear again that the pressure would be greatly increased. The density of mercury is 14 times that of water, and the pressure would be increased in this ratio. The pressure due to a column of water depends, therefore, not only on its height but also on the density of the liquid.

**EXPERIMENT 24. — To find how the pressure in a liquid varies with the depth.** The apparatus consists of a thistle funnel F, the end of which is closed by a tightly stretched membrane M (fig. 85). The other end of the funnel is attached by rubber tubing to a U-tube G, containing water coloured with red ink. When the funnel is lowered into a gas cylinder containing water, the latter exerts an upward pressure on the membrane, and this pressure is transmitted by the air in F

and in the tubing to the liquid in the U-tube. It will be found that the liquid in the left-hand side of the U-tube (or **manometer**, as it is often called when used to measure pressure) falls owing to this pressure, while the level of the liquid in the other side rises. The greater the difference of levels  $b$  between the two sides of the manometer, the greater the pressure. Lower  $F$  to varying depths in the water in the gas

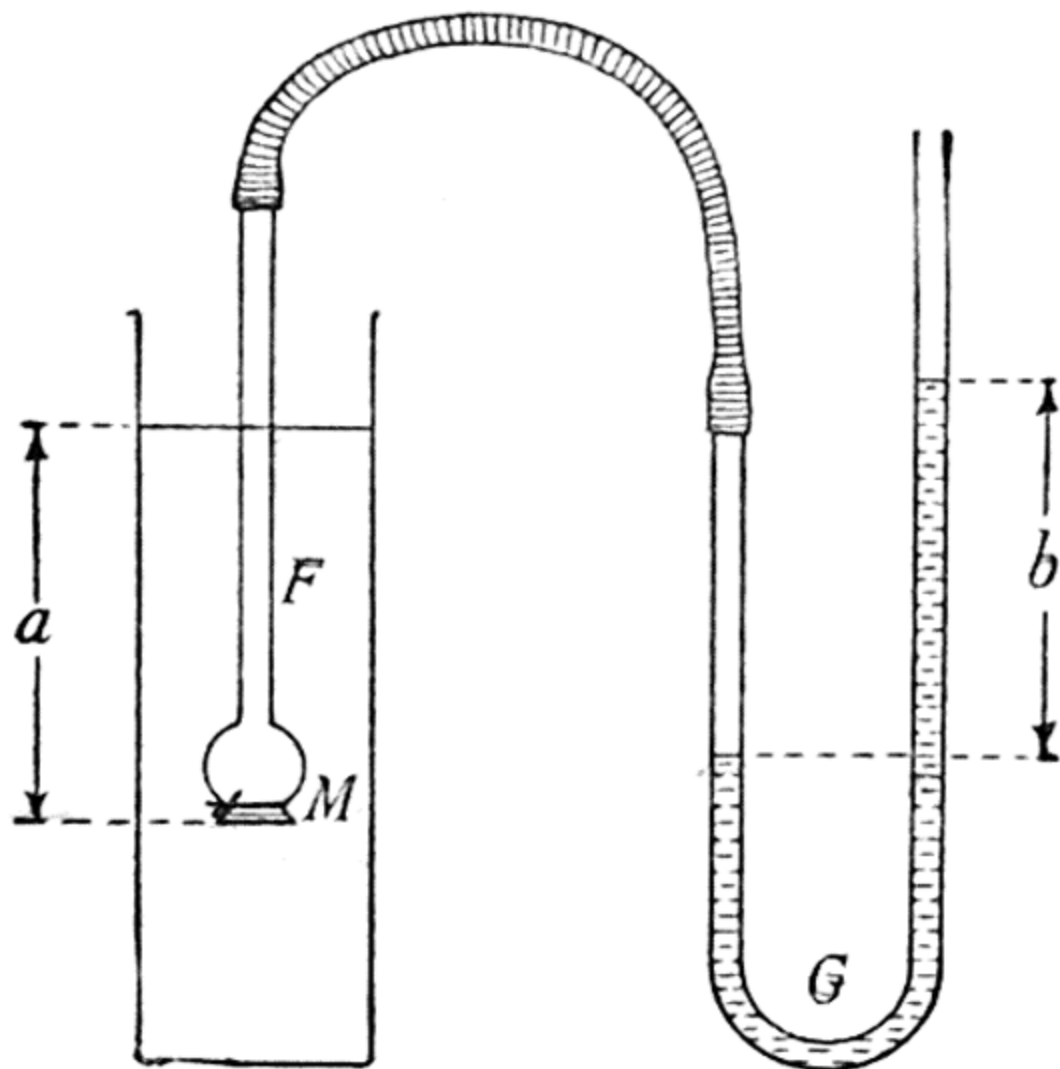


Fig. 85. — To show that the pressure in a liquid varies with the depth

cylinder and measure each time the depth  $a$  of the membrane  $M$  below the surface, and the difference of levels  $b$  on the manometer.

✓ **EXPERIMENT 25. — To show that the pressure due to a column of liquid is independent of the shape of the vessel (Pascal's Experiment).** The apparatus, invented by Pascal (1623–1662), consists of a column  $A$  carrying a brass ring  $B$ , into which can be fitted the brass rings round the bottoms of glass vessels  $P$ ,  $Q$ , etc., of different shapes (fig. 86). Lower ends of the vessels are closed by a flexible membrane which has the same area in each vessel. When a vessel is placed in the brass ring  $B$ , the weight of the vessel is taken by the ring, but if liquid is placed in the vessel the pressure of the liquid causes the membrane to bulge downwards, and so work the lever  $CD$ , which is pivoted at  $E$ . The greater the pressure, the more the membrane bulges, and so the farther the pointer moves up the scale  $F$ .

If P, Q, etc., are placed in B in turn and filled with water to the same height, it will be found that the pointer indicates the same pressure each time, although P contains a greater weight of water than Q. Since the pressure on each membrane is the

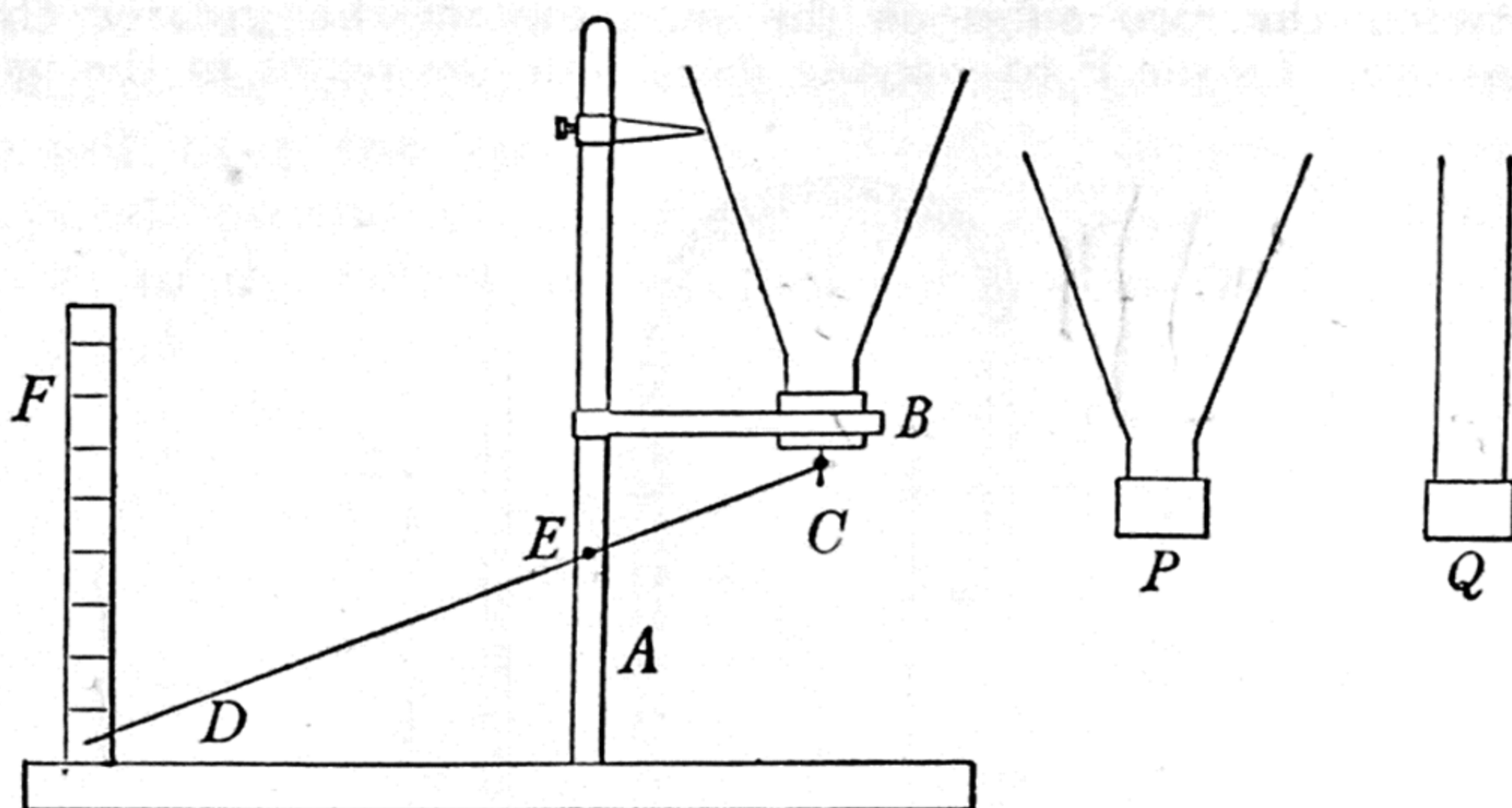


Fig. 86. — Pascal's Vases

same, and each has the same area, it follows that the total downward force on the membrane does not depend on the weight of water in the vessel. P contains more water than Q, but the extra weight of water is supported by the sloping sides.

To sum up the facts we have learned so far about liquid pressure: liquid pressure is

- (1) proportional to the height of the liquid column;
- (2) proportional to the density of the liquid;
- (3) independent of the shape of the vessel; and
- (4) it acts at any point equally in all directions.

If we have a U-tube fitted with a tap T (fig. 87), and containing columns of water of different heights, the pressure at A, the base of the left-hand column, is greater than that at B, the base of the right-hand column. Since this pressure acts equally in all directions at A and B, it is transmitted as a horizontal pressure by the

liquid in the bottom of the tube, and so we have a pressure acting on the tap, towards the right on the

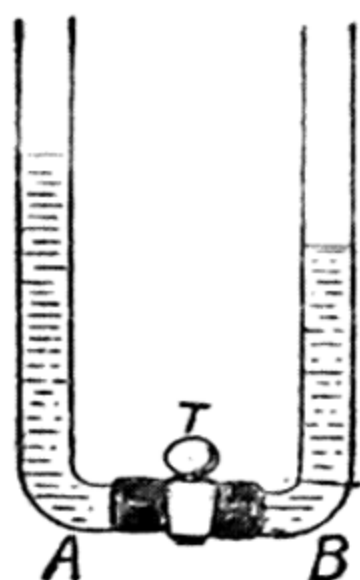


Fig. 87. — A tube fitted with tap

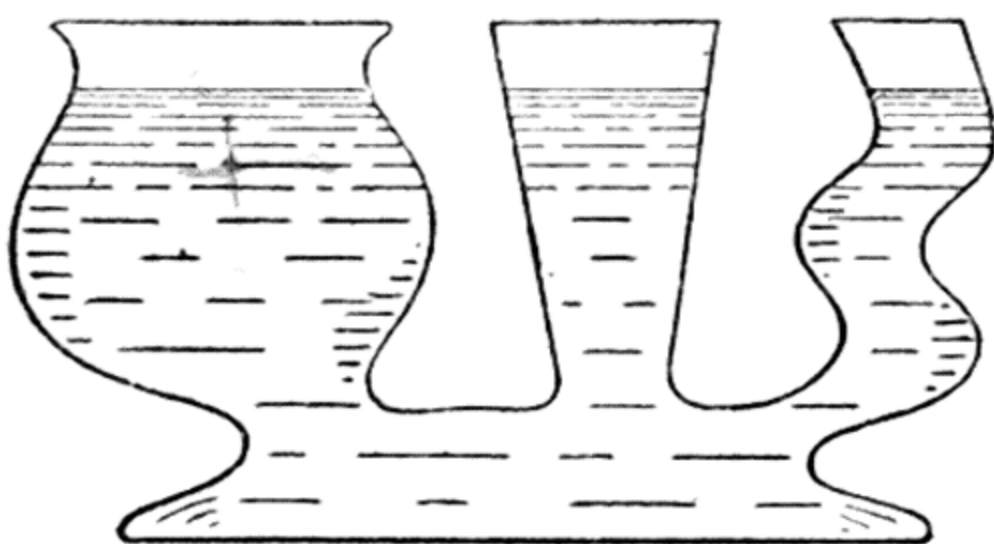


Fig. 88. — A liquid finds its own level

left-hand side of the tap, and towards the left on the right-hand side of the tap. The former pressure will be greater than the latter, so that when the tap is opened water will flow from the left-hand side to the right until the two pressures are the same, i.e. until the water stands at the same height in both limbs. This is sometimes expressed by saying that “water finds its own level” — if it is given an opportunity to do so (fig. 88).

### The Water Gauge.

This principle is made use of in the **water gauge**. When we boil water in a copper can, the can will be damaged if we allow all the water to boil away. In order that we may see how much

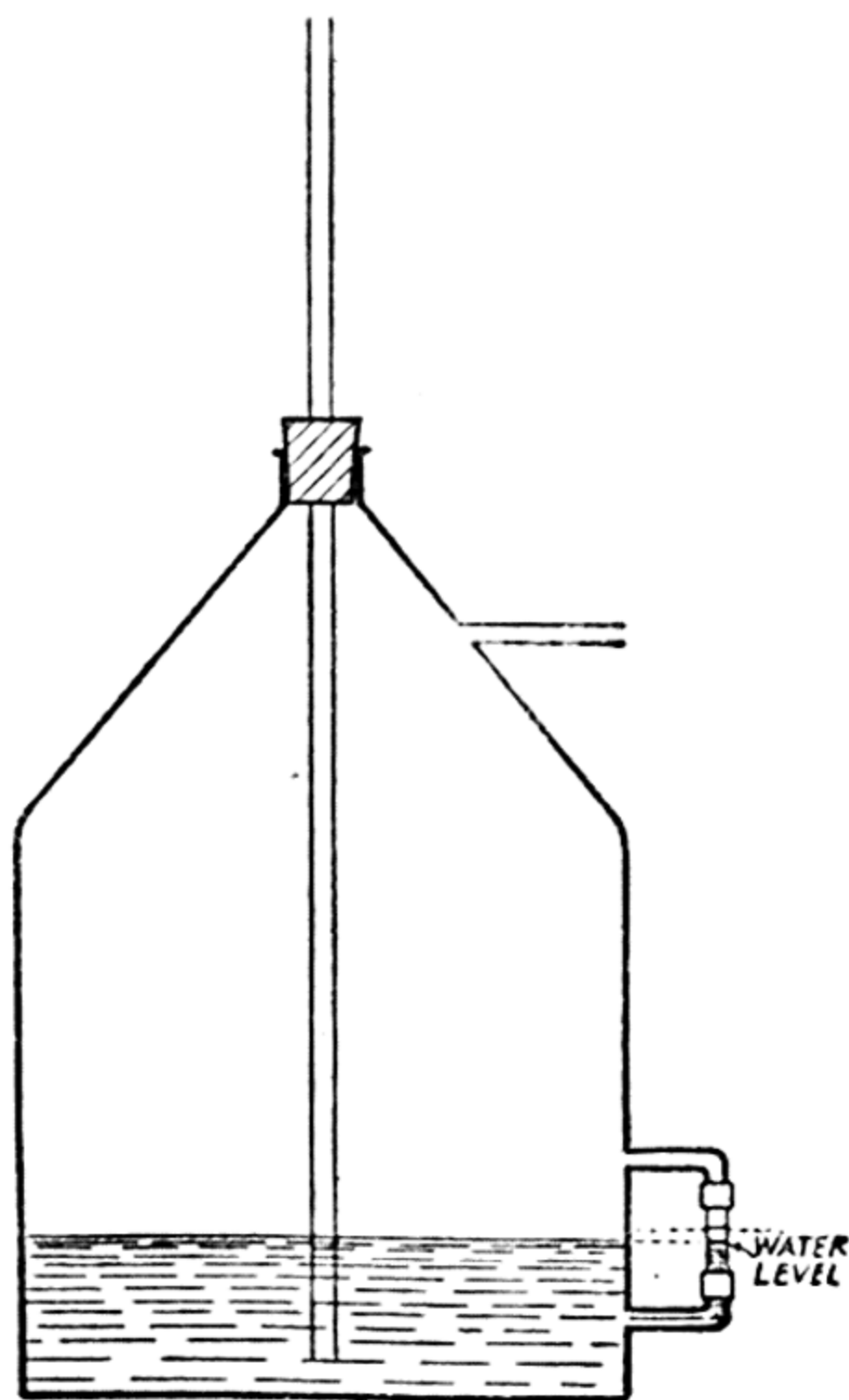


Fig. 89. — A Boiling Can with Water Gauge

water is left, a short vertical glass tube is attached by pieces of rubber tubing to two metal side-tubes from

the boiling can. The water stands at the same level in the glass tube as it does in the can (fig. 89). Some petrol gauges on motor cars work in the same way.

### Artesian Wells.

These also depend on the fact that water finds its own level. The surface of the earth, below the soil, consists of layers or **strata** of various kinds of rock, some porous, like chalk or limestone, and others, such as clay and shale, not porous. When we have a porous

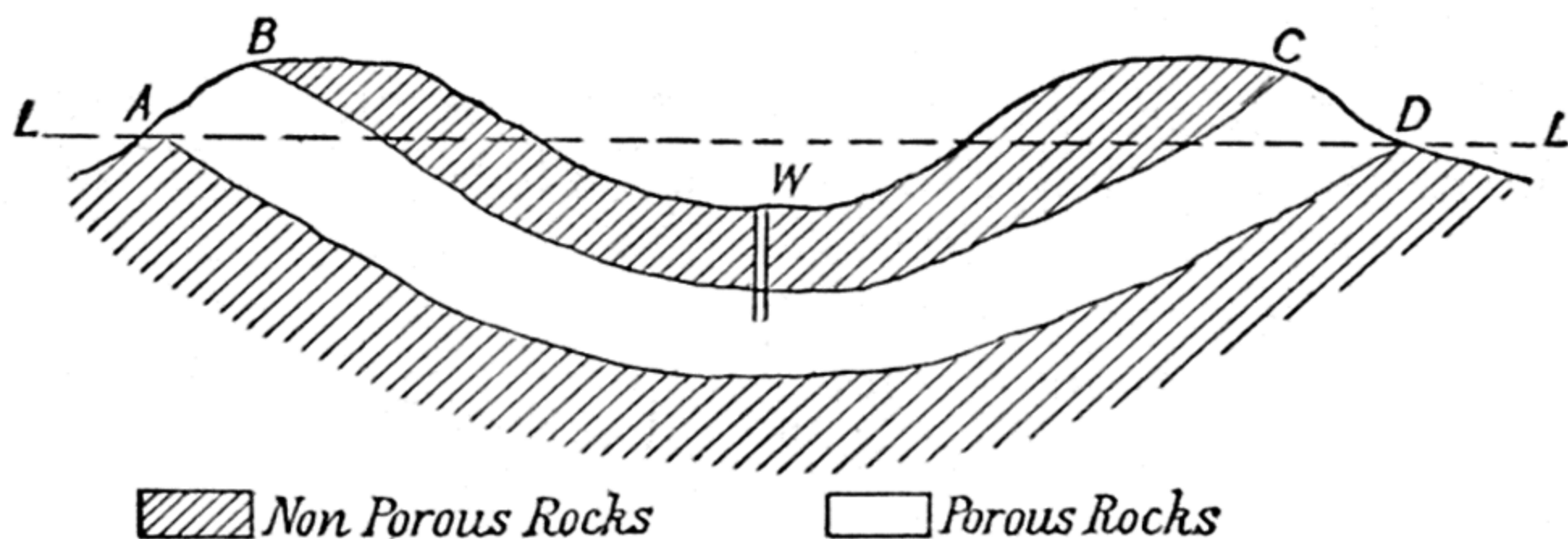


Fig. 90. — Artesian Well

rock sandwiched between two non-porous layers; all arranged in the shape of a saucer, rain falling at AB and CD (fig. 90), where the porous rock comes to the surface, or **outcrops**, drains down into the bottom of the porous layer and cannot escape. The porous rock gradually fills with water up to the level LL, when it forms **springs** at A. If a well is sunk at W, the water rises and flows out of the well, sometimes with considerable force. Such wells are common in certain parts of Australia, but are used in all parts of the world where the rock formations are suitable.

EXPERIMENT 26. — To find the density of paraffin by the method of balancing columns. Join two pieces of glass tubing at one end by rubber tubing so as to form a U-tube, and pour water into the tube by means of a drawn-off thistle funnel until it stands some inches above the bend (fig. 91, a).

Now pour paraffin-oil down the left-hand tube. The level of the water will fall in the left-hand tube and rise in the other (fig. 91, *b*). Let AB represent a horizontal line through the common level of the oil and water, i.e. where the liquids meet. The height  $h_1$  of the water column above the common level will be less than the height  $h_2$  of the paraffin column above the same level. Since these two columns balance, the pressure at the bottom of each tube must be the same. The liquid below the level AB is water on both sides, and is therefore self-balancing. That is, the pressure due to  $h_1$  cm. of water on the

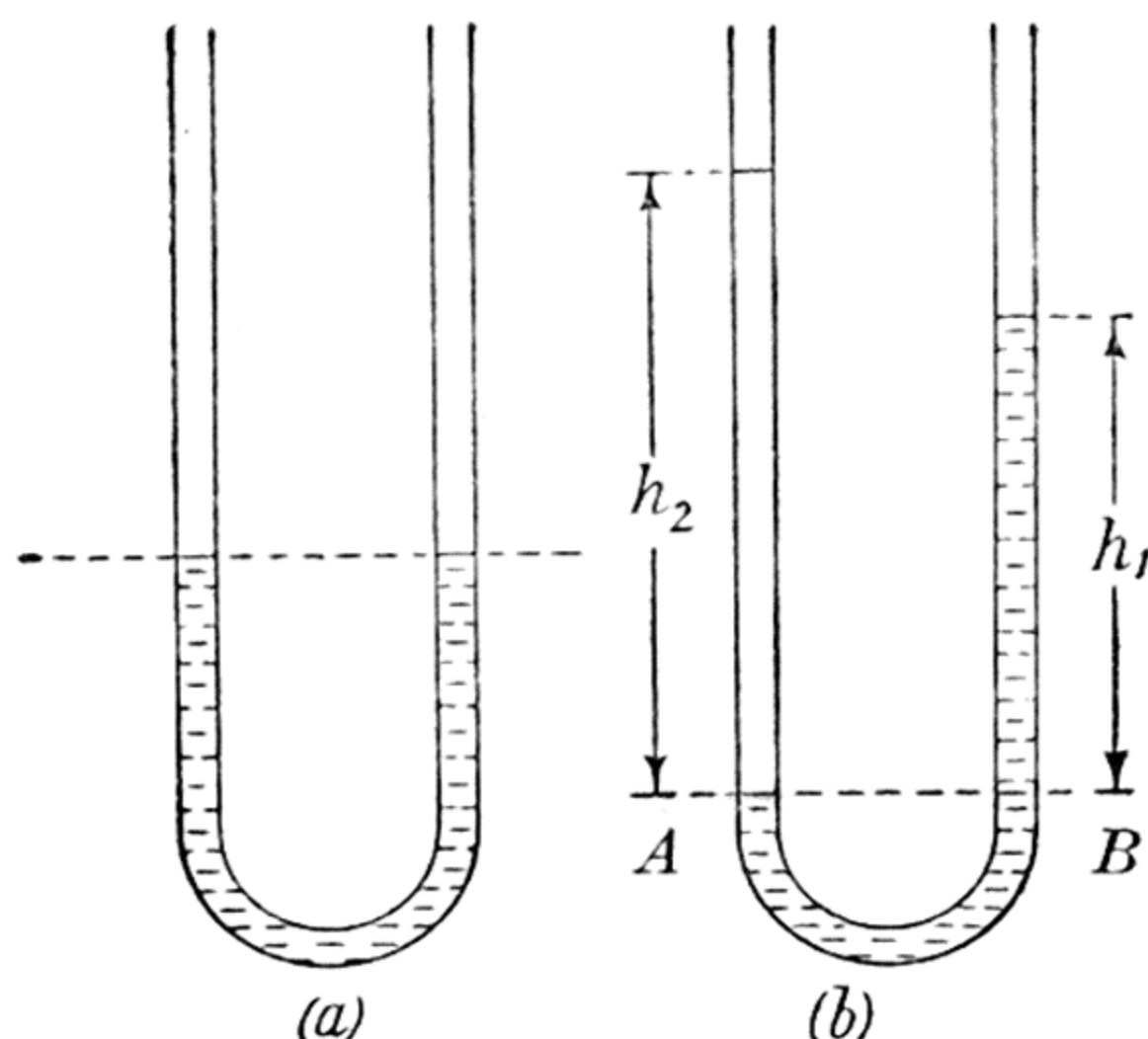


Fig. 91. — Density of Liquids by U-tube Method

right-hand side must be equal to the pressure due to  $h_2$  cm. of paraffin on the left-hand side. The density of water is 1 gm./c.c., so that the water pressure is equal to  $h_1 \times 1$  gm. weight per sq. cm., and if  $d$  gm./c.c. is the density of paraffin, the pressure of the paraffin column is  $h_2 \times d$  gm. weight per sq. cm.;

i.e.

$$h_1 \times 1 = h_2 \times d,$$

$$d = \frac{h_1}{h_2}.$$

$h_1$  and  $h_2$  are measured with a centimetre scale, and so  $d$  can be calculated.

If, in the above experiment, the liquid in the right-hand side, instead of being water, had had a density

$d_1$  gm./c.c., we should have had in a similar manner

$$h_1 \times d_1 = h_2 \times d_2,$$

so that

$$\frac{d_2}{d_1} = \frac{h_1}{h_2},$$

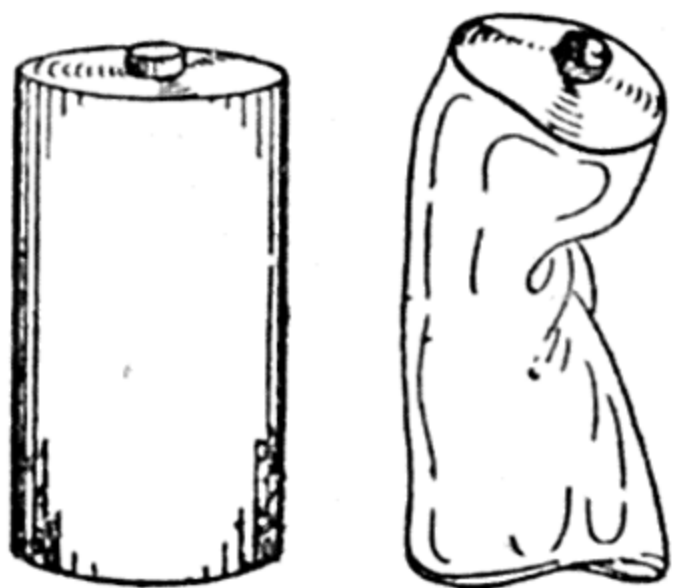
where  $d_2$  is the density of the other liquid, i.e. the densities of the liquids are inversely proportional to the heights of their respective balancing columns. Obviously, this method can be used only if the two liquids do not mix.

### The Pressure of the Atmosphere.

Since air and other gases resemble liquids in having weight, we should expect them to exert pressure also, and this they do. The column of air above the surface of the earth is many miles high, so that, although the density of air is small, the resulting pressure is as high as 15 lb. weight per square inch.

**EXPERIMENT 27. — To show the pressure of the atmosphere.**

(a) Take a thin-walled metal can, put a couple of inches of water in the bottom and boil the water briskly for two or three minutes. The steam formed



drives out all the air from the can. Remove the flame and simultaneously put a well-fitting rubber cork in the mouth of the can. Allow the can to cool down, or pour cold water on it. The steam inside it condenses, and the pressure of the air outside crushes in the walls of the tin (fig. 92). The tin does not collapse while it is full of air

or steam, because these exert a pressure outwards on the walls of the can, counter-balancing the inward pressure of the atmosphere.

(b) Join a straight barometer tube by means of a short piece of pressure tubing to another glass tube about a foot long, and secure the rubber tubing by wiring it on. Hold the

tubing in an inclined position and almost fill it with clean dry mercury from a drawn-out thistle funnel. Put a finger over the open end and slowly raise the closed end. The air-bubble from the open end will rise to the closed end and collect any small bubbles of air sticking to the glass. Now raise the open end so that the air-bubble returns. Tilt the short tube downwards and run out mercury until it contains only about two inches of mercury. Fix the two tubes in a vertical position (fig. 93). The mercury will be found to stand about 30 in. higher in the closed arm than in the other. This 30 in. of mercury is balanced by the pressure on the open tube due to the atmosphere. The mercury in the closed tube has no air above it (test this by tilting the closed tube sideways until the mercury fills the tube. If the space above the mercury is a vacuum a sharp metallic click will be heard as the mercury strikes the top of the glass tube), and so there is no corresponding pressure on the left-hand side. Note that when the tube is tilted sideways the length of the mercury column increases, but the **vertical** height of the column remains the same.

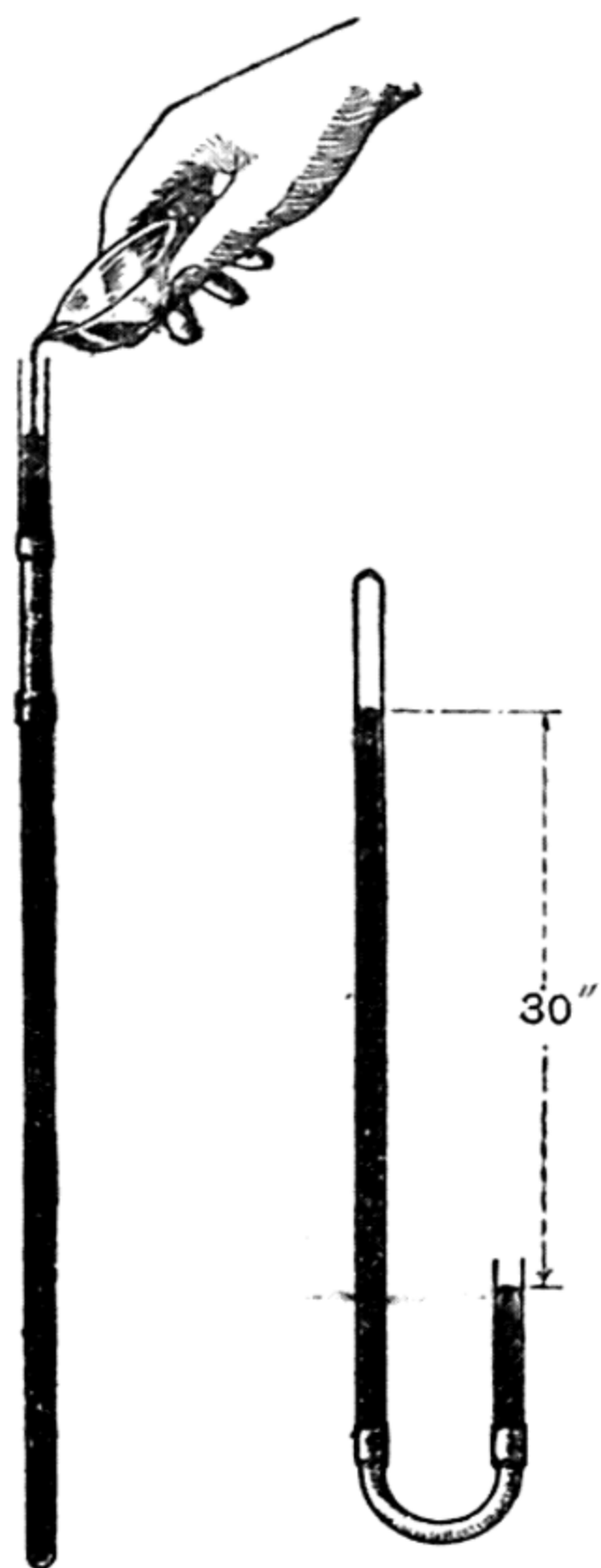


Fig. 93. — Setting up a U-tube Barometer

## The Barometer.

When we were considering liquids in open U-tubes, we neglected the pressure of the atmosphere because it was the same on both limbs.

It is not necessary to have a U-tube in order to measure atmospheric pressure. A straight tube filled with mercury and then inverted in a pool of mercury will do just as well, and is, moreover, simpler. The pressure at P inside the tube (fig. 94) is that due to the column of mercury, while that at Q, at the

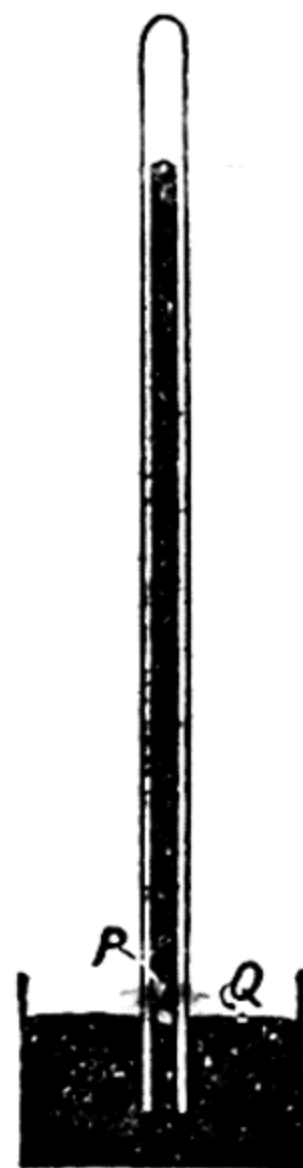


Fig. 94

same level as P but outside the tube, is due to the atmosphere. If these pressures were not equal, mercury would move from the one where the pressure was higher to the other.

At one time people did not believe that mercury rose in a barometer tube because of the pressure of the air on the mercury in the open dish, and Pascal endeavoured to prove it by sending a barometer to his brother-in-law, who lived in Auvergne, and asking him to take it to the top of the Puy de Dôme, 4800 ft. high. Since

at that height the column of air above the mercury was 4800 ft. less than at sea-level, the height of the barometer should not be so great, and so it proved, for the height of the barometer was  $3\frac{1}{2}$  in. less at the top of the mountain than at its foot. We can show the same thing more easily in another way.

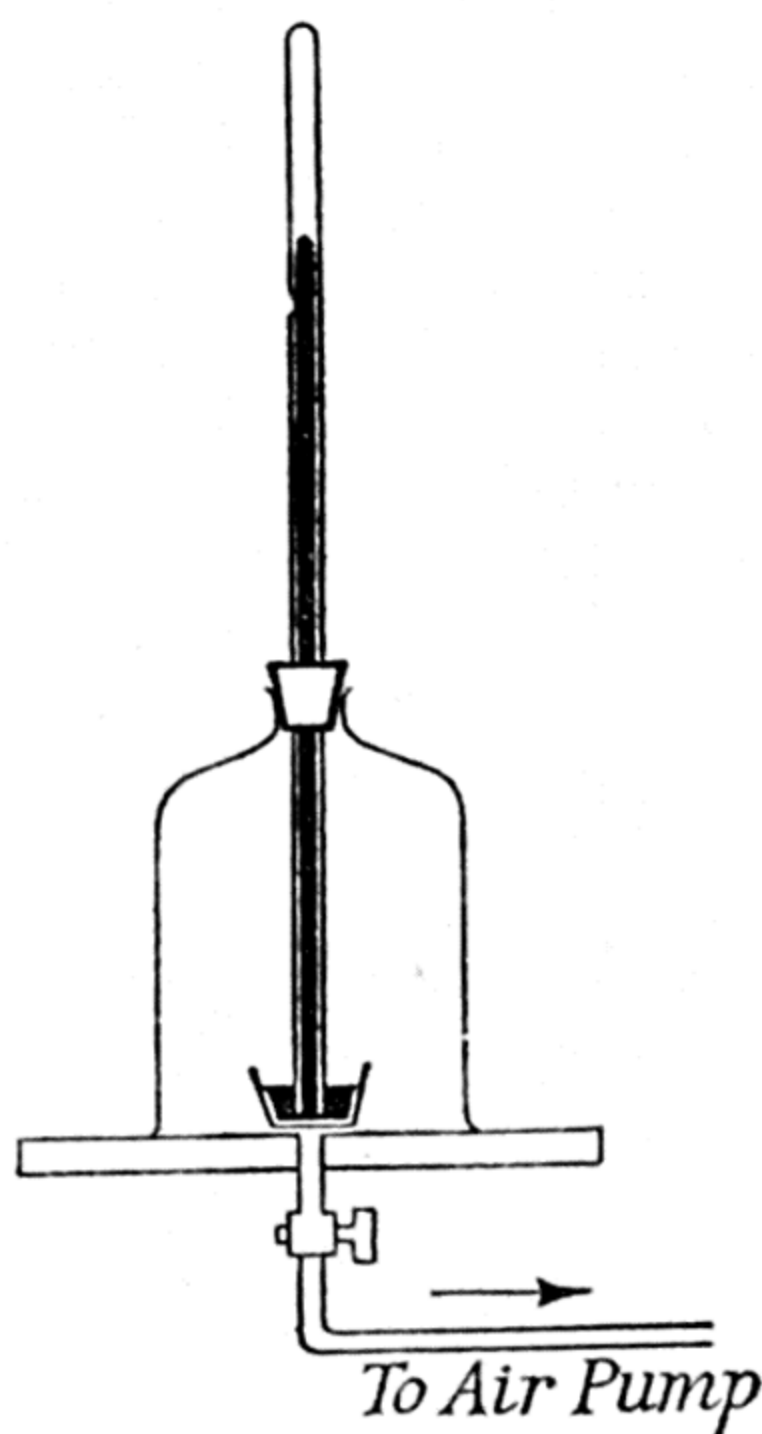


Fig. 95. — Apparatus to show that the column of mercury in the barometer tube is supported by the pressure of air in the bell-jar.

**EXPERIMENT 28. — To show that the height of the barometer depends on the pressure of the atmosphere.** Arrange a barometer with its dish of mercury on the plate of an air-pump (fig. 95). Grease well with vaseline the flange of a bell-jar, and place it on the plate of the pump so that the barometer tube passes through the mouth of the jar. Slip a rubber cork down the barometer tube until it closes the mouth of the bell-jar. On working the air-pump, and thus withdrawing the air from the bell-jar, the level of the mercury in the barometer falls. On opening

the valve of the pump the air can be heard hissing in and the level of the mercury again rises.

## Weather and the Barometer.

Although the height of the barometer in this country is usually about 30 in., it varies from day to day, and with these changes are associated changes in the weather. At one time it was thought that when the barometer was low the weather would be wet or stormy, and that when it was high the weather would be fine. We realize now that this is not always true, that what really matters is whether the pressure of the atmosphere is **increasing** or **decreasing**. A rising barometer indicates fine weather and a falling one stormy weather. These changes of pressure are brought about by the presence in the upper atmosphere of masses of cold, dense air, or of warm, less dense air, as the case may be, that have come from other regions of the globe. When the atmosphere contains, for example, cold, dense air the pressure of the atmosphere is higher than it would otherwise be.

## Types of Barometer.

The pressure of the atmosphere is given in the barometers described on p. 115 by the distance between the mercury levels in the open and closed tubes, in the one form, and between the level in the tube and that in the pool, in the other. When one level rises, the other falls, so that the zero of our measuring scale, which is the level of the open mercury surface, is continually changing. To overcome this difficulty, the instrument used in accurate work (the **Fortin** barometer, fig. 96) has the mercury pool enclosed in a leather bag A, the bottom of which can be raised or lowered by means of the screw B, so that the level of the mercury can be brought to the ivory point C. This is done each time before the instrument is read. Engraved on the metal case is a scale, the zero of which is at C.

Ordinary household barometers are either of the tall

type (fig. 97) or else are **aneroid** barometers (fig. 98). The former is a U-tube or siphon mercury barometer, on the open end of which floats a metal weight, the rise and fall of which causes the pointer to

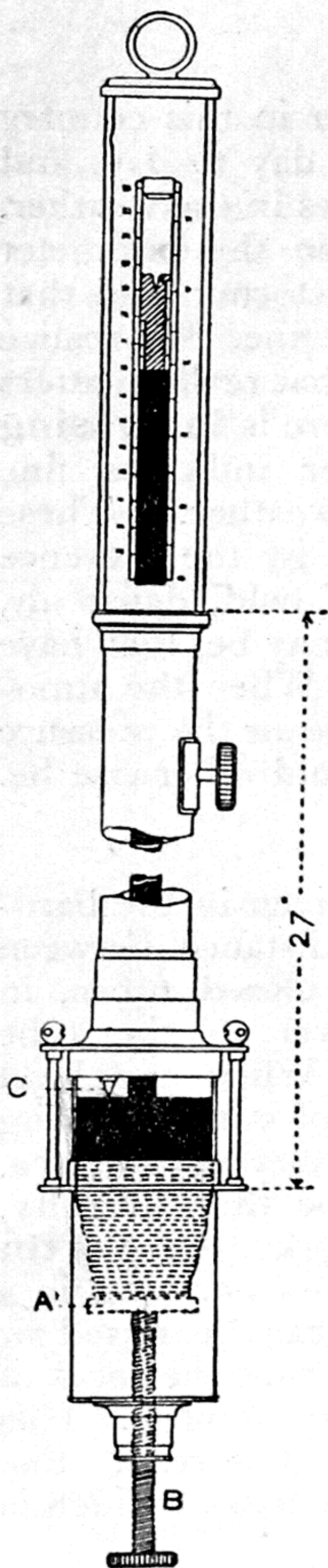


Fig. 96. — Fortin Barometer

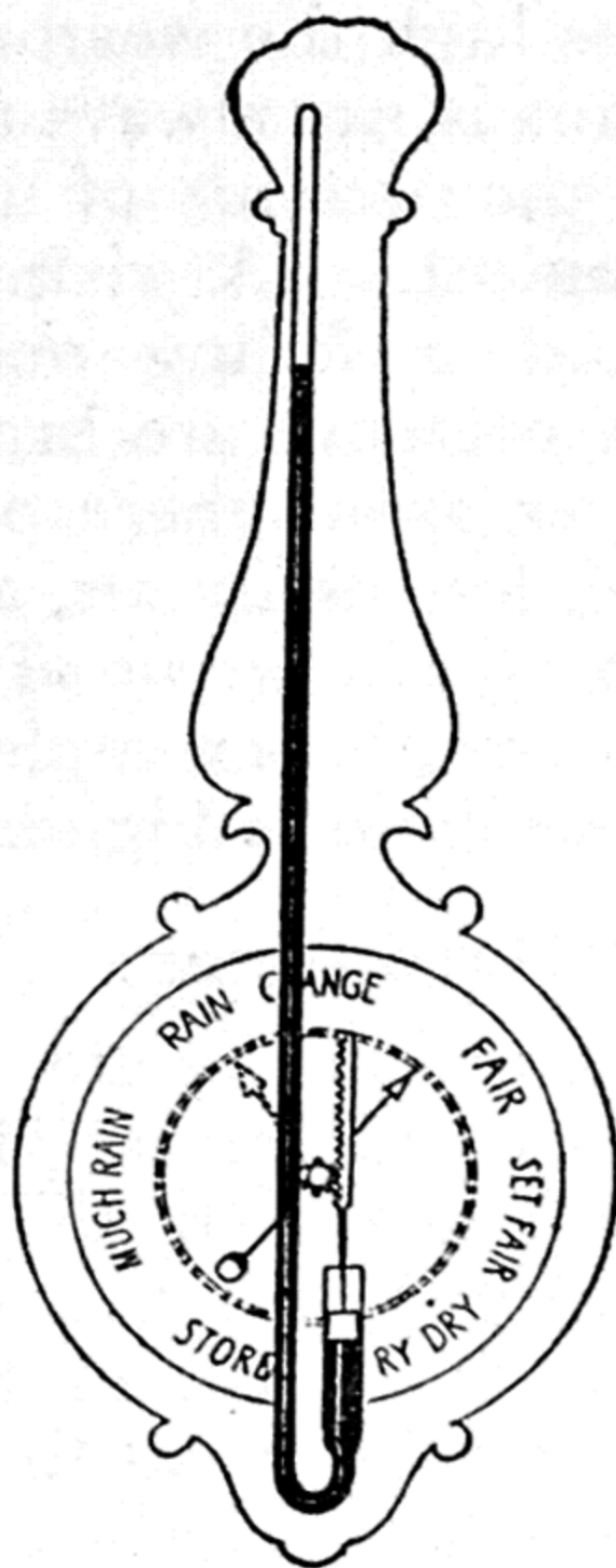


Fig. 97. — Household Mercury Barometer

move round the graduated scale, either by a rack and pinion movement, as shown in the figure, or sometimes by means of a chain passing over a cog-wheel.

The **aneroid** barometer works on quite a different principle. It consists of a metal box with a thin corrugated

metal lid. The box is exhausted of air, and an increase or decrease in atmospheric pressure causes the lid to move inwards or outwards as the case may be. This movement of the lid is multiplied by a suitable system of levers, and causes a pointer to move over a scale. The scales of both siphon and aneroid barometers are graduated by comparison with a standard (i.e. a Fortin) barometer. The aneroid barometer is a much smaller, cheaper and more convenient instrument

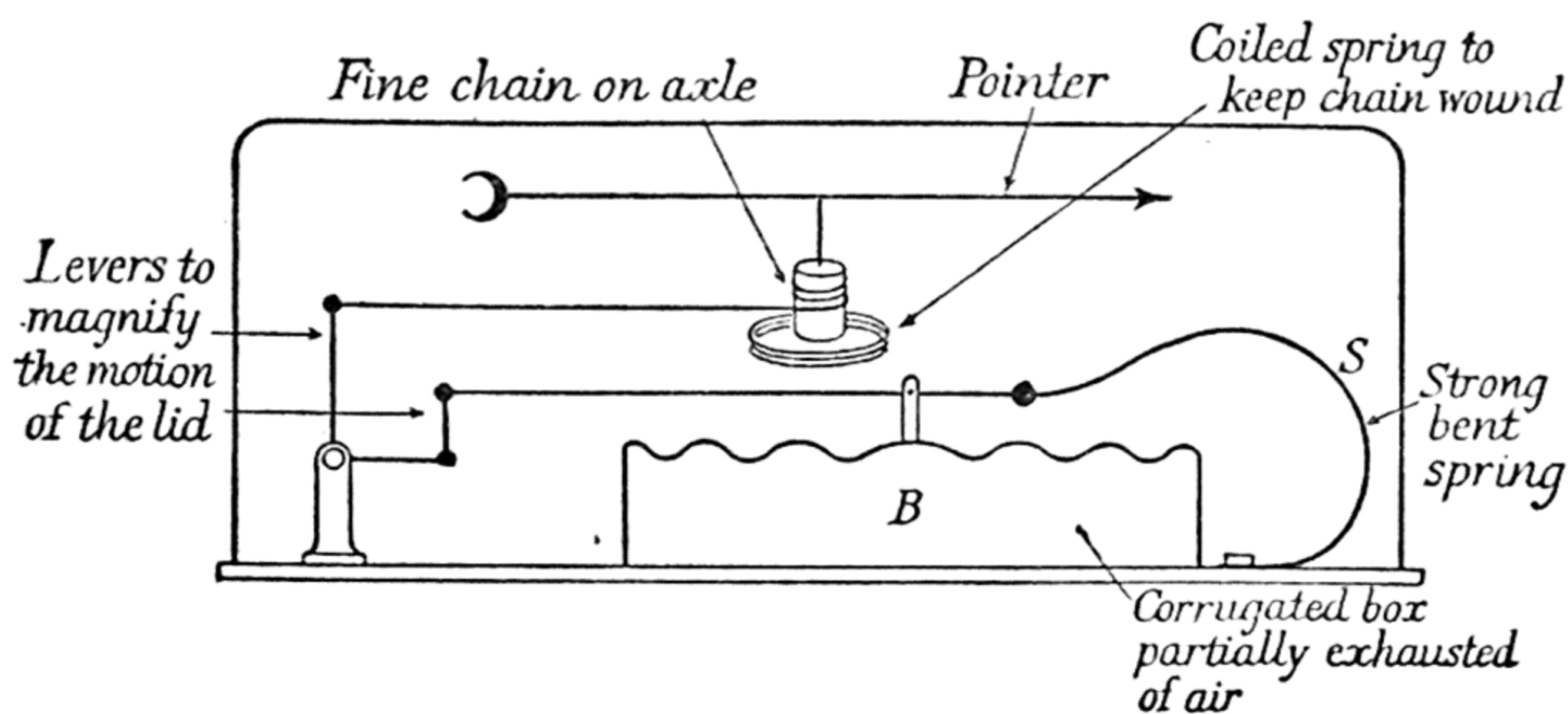


Fig. 98. — Diagrammatic representation of an Aneroid Barometer

than a mercury barometer, but it is not so accurate as the Fortin type.

The **barograph**, or self-recording barometer, consists of an aneroid instrument, the pointer of which carries an inked brush that makes a mark on ruled paper corresponding to the barometric height. The paper is carried on a slowly rotating drum, so that a continuous record may be obtained.

## ✓ The Barometer as a Height Measurer.

We have seen that the pressure is less at the top of a mountain than at sea-level. The height of the barometer diminishes at first about 0.1 in. for each 90 ft.

increase in altitude, but at greater heights the change is less. Hence a barometer can be used to measure altitude, and, when used in this way, the instrument is called an **altimeter**. Altimeters used by airmen consist of small aneroid barometers fitted with an adjustment so that the pointer can be set at zero to start with. As the airplane rises the atmospheric pressure on the instrument diminishes and the pointer moves over the scale. This scale is graduated, not in inches or centimetres of mercury, but to read the height directly in feet. The reading represents height above the starting-point and not height above ground at a given moment, so that if the airplane started from sea-level, the instrument would read 2000 ft., although the airplane might be passing only 500 ft. above a hill 1500 ft. high. A further difficulty is the fact that the barometric pressure at sea-level changes from place to place, and from time to time. On a long flight this may cause serious error, since it will affect the altimeter just as change in altitude will affect it. The sealed altimeters carried by airmen on attempts at altitude records are barographs, sealed so that they cannot be tampered with. From the lowest pressure recorded, the greatest height reached can be calculated.

A barometer can be constructed using water instead of mercury, but because of the smaller density of the water the atmosphere can support a column of it about 34 ft. in height. Such an instrument would be much too cumbersome to be useful, and moreover, owing to the considerable change in density of water as its temperature changes, and for other reasons, it would not be particularly accurate. A working barometer employing glycerine as the liquid was formerly on view at the side of the main staircase at the Science Museum, South Kensington.

## Boyle's Law.

If a finger is placed over the outlet of a bicycle pump and the handle of the pump is pushed down, the resistance to further movement of the handle rapidly increases. This is because the air in the pump, unable to escape, is compressed, and, as its volume diminishes, its pressure increases. If the handle is now released, the excess pressure of the air in the barrel over that of the air outside will force the handle out again.

**EXPERIMENT 29.** — To find how the pressure of a given mass of gas varies with its volume. A U-tube is made by joining together with a piece of pressure tubing two lengths of glass tubing, one of which is closed. The right-hand limb (fig. 99) is graduated in c.c. from the top, as in a burette, and contains dry air enclosed by mercury. The pressure of the air in the right-hand limb is equal to that of the atmosphere, plus that due to a column of mercury  $h$  cm. in height. If the height of the barometer is 75 cm., and  $h$  is equal to 10 cm., then the pressure of the gas in A is 85 cm. On pouring more mercury into the left-hand limb, the level will rise more rapidly in that limb than in A, so that different values of  $h$  can be obtained, the volume of air becoming smaller as  $h$  increases. A number of readings are taken and set down as follows:

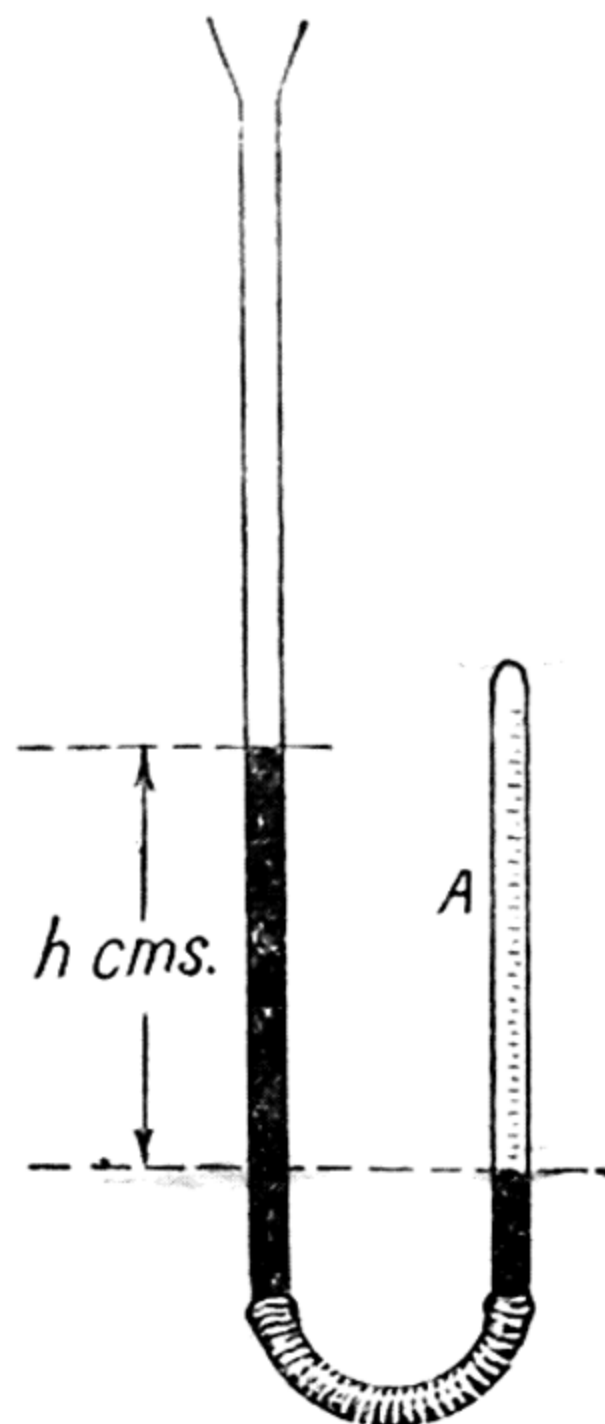


Fig. 99. — Boyle's Law Apparatus

Difference of Mercury Levels $h$	Atmospheric Pressure	Total Pressure on Enclosed Air	Volume of Enclosed Air	Pressure $\times$ Volume
10 cm.	75 cm.	85 cm.	20 c.c.	1700
20 cm.	75 cm.	95 cm.	18 c.c.	1710

It will be seen from the results of the above experiment that the product of the pressure of the gas and its volume, in column 5, remains very nearly constant. That is, when we *increase* the pressure on a gas, its volume *diminishes* in the same ratio. If we double the pressure, the volume is halved; if we treble the pressure, the volume is reduced to one-third of its original value, and so on. We express this by saying that **the volume is inversely proportional to the pressure.** Although we used air in our experiment, similar results would have been obtained with other gases.

This relationship was first discovered by the Hon. Robert Boyle (1627–91), one of the founders of the Royal Society, and has been named after him ever since. Boyle's Law is generally stated in this form:

**The volume of a given mass of gas is inversely proportional to its pressure if the temperature remains constant.**

It should be noted that the relationship holds only if the temperature remains constant, because when a gas is heated it expands even although the pressure on it remains the same. In our experiment the gas remained at room temperature the whole time, and this does not change appreciably during the time taken to perform the experiment.

### **Scientific Laws.**

The term "Law" used in science has a very different meaning from the "law" of the land. The "law" of the land tells us what we ought to do and what we ought not to do and specifies the penalties for disobedience. If we are prepared to pay the penalty there is usually little difficulty in breaking a law of the land. A scientific Law is merely a statement giving in a few words the results of a great number of experiments. There is no

compulsion implied in a scientific law, which only *describes* the way in which things are found to behave. Very few scientific laws are *exactly* true. Boyle's Law is very nearly true in the case of air, but does not tell us so accurately how the volume of such a gas as carbon dioxide changes with change in pressure.

### The Lift Pump (fig. 100).

The ordinary pump, or lift pump, consists of a cylinder in which a piston can be moved up and down by means of a handle. The cylinder communicates by a pipe with the water to be raised. There is a valve  $V_2$  in the piston and another  $V_1$  at the top of the pipe, both opening upwards. When the piston is raised the air below the piston expands, and so its pressure falls. Valve  $V_2$  closes because the pressure above it is greater than that below it, while valve  $V_1$  opens because the pressure above it is less than that below it. Air passes from the pipe into the cylinder, and so the air pressure in the pipe falls. The greater atmospheric pressure on the water outside the pipe causes water to be forced up inside the pipe. When the piston descends the air in the cylinder is compressed, so that valve  $V_1$  closes and valve  $V_2$  opens. The air originally in the cylinder passes out. On raising the piston again more air from the pipe enters the cylinder and the pressure falls further in the pipe, so that the water rises higher in it. Eventually, water rises into the cylinder on the

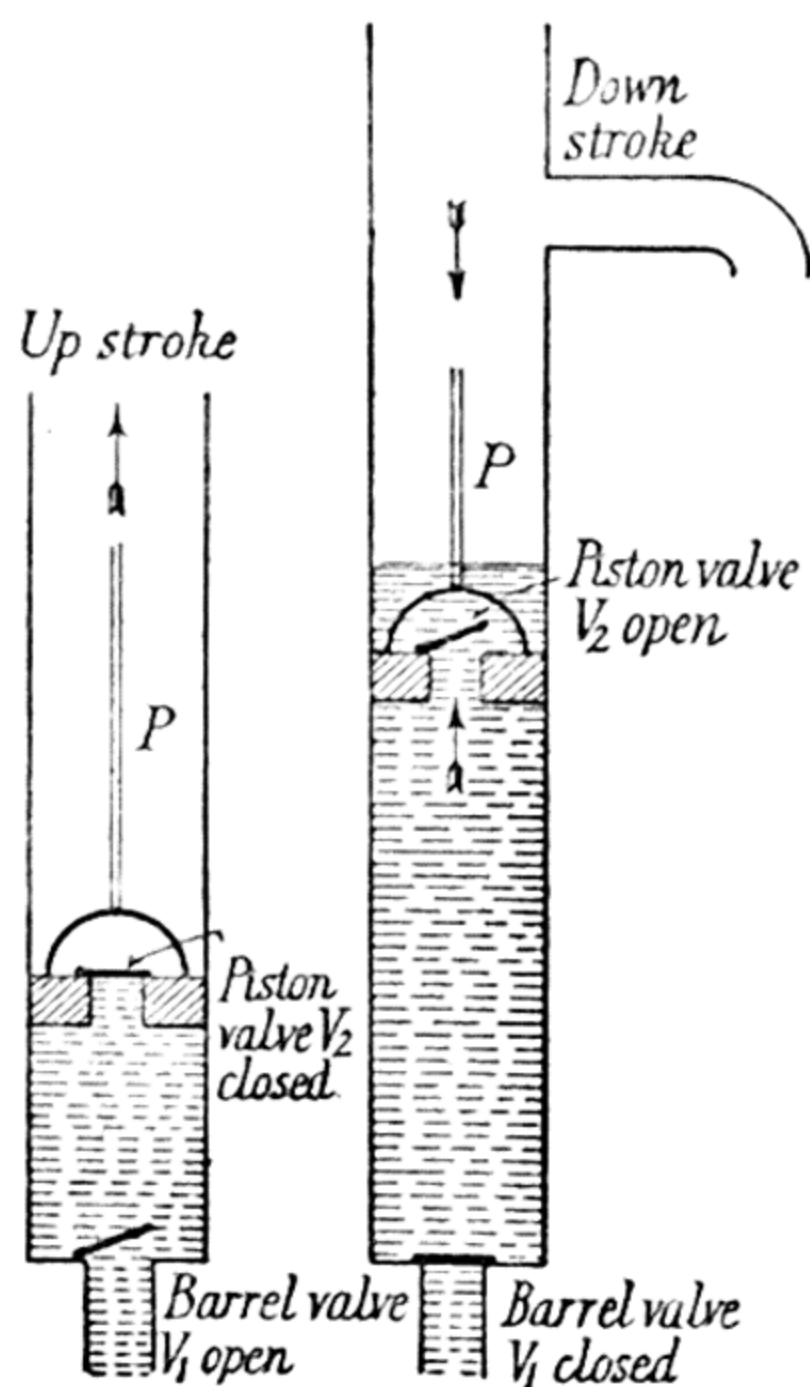


Fig. 100. — Lift Pump

up-stroke, passes above the piston at the down-stroke, and is raised by the next up-stroke to the level of the outlet.

Until after the time of Galileo (1564–1642) people believed that the lift pump worked because a vacuum was formed above the water in the pipe and that, since “nature abhors a vacuum,” water was sucked up by the vacuum to fill its place. We now know that a vacuum can exert no suction whatever and that the water is forced up by the pressure of the atmosphere outside. In theory, the outlet could be as much as 34 ft. above the level of the water to be raised, because that is the height to which water will rise in a tube if all the air is removed from it, i.e. that is the height of the column of water that can be supported by atmospheric pressure. In practice, owing to the weight of the valves and for other reasons, the limit is about 26 ft.

If the piston of a lift pump does not fit very well, air may escape round the edge when the valve  $V_2$  is closed. To prevent this a pump is sometimes “primed” by pouring in a little water above the piston before commencing to pump.

### The Force Pump.

When we wish to raise water to a height greater than about 26 ft. we use a force pump (fig. 101). This has a solid plunger without a valve, a valve  $V_2$  at the entrance to the outlet, and another valve  $V_1$  at the top of the pipe. As the piston rises  $V_2$  closes and  $V_1$  opens. When the piston falls  $V_1$  closes and  $V_2$  opens. Water drawn into the barrel during the up-stroke is forced out through the outlet, and the height to which it can be forced depends only on the force applied to the piston and therefore to the pressure applied to the water in the cylinder.

In both the above pumps water is delivered only when the plunger is moving one way — upwards in the

case of the lift pump, and downwards in the case of the force pump. For some purpose, e.g. for supplying a fire hose, a continuous supply is required. This can be obtained by connecting two force pumps with a common outlet and arranging so that the piston of one pump is moving downwards while that of the other pump is moving upwards. Further equalization of pressure is secured by forcing the water into a chamber containing air (A, fig. 101). When the piston on the down-stroke is forcing water out of the barrel, the air is compressed, and when the piston is rising, this compressed air expands and helps to force water out of the jet.

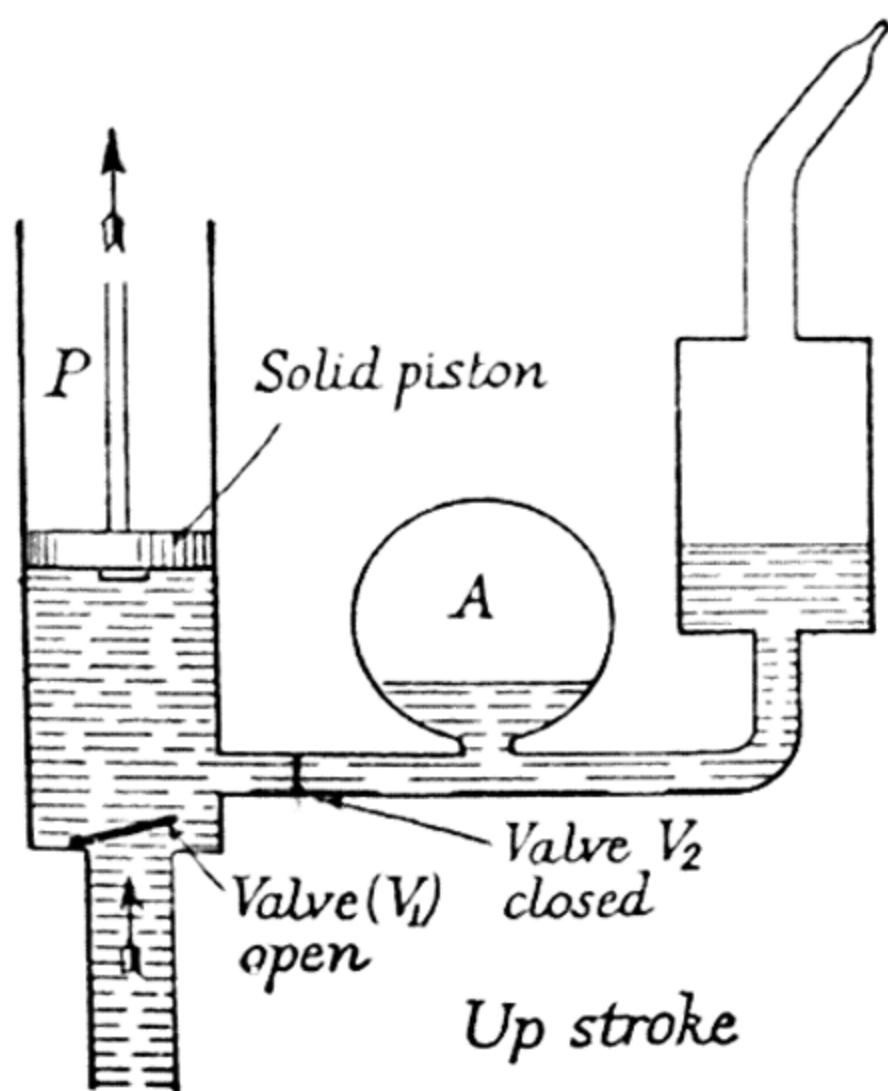


Fig. 101. — Force Pump

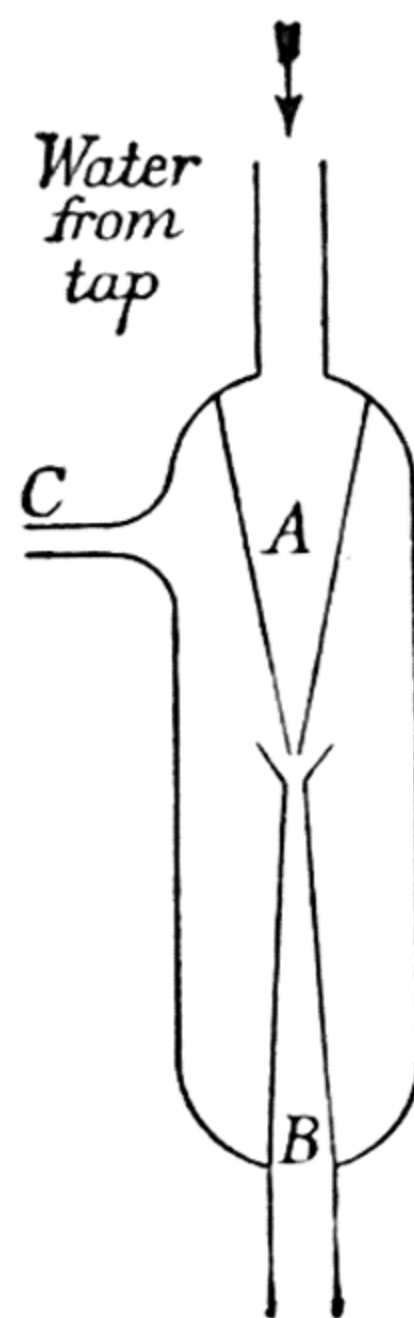


Fig. 102. — Filter Pump

### The Filter Pump.

The filter pump (fig. 102) can be used for removing air from an apparatus. It gets its name from the fact that it is often used to speed up the process of filtration (see p. 151). Water from a tap passes as a powerful jet

from the tapering tube A into another tapering tube B. Air from the apparatus to be exhausted enters the pump at C, and bubbles of air, entangled in the jet, are carried down the outlet tube. Such a pump will exhaust apparatus to a pressure of 3 or 4 cm. of mercury.

### The Bicycle Pump.

The bicycle pump (fig. 103), is a compression pump and not an exhaust pump. The only valve in the pump is a cup-shaped washer of leather on the end of the

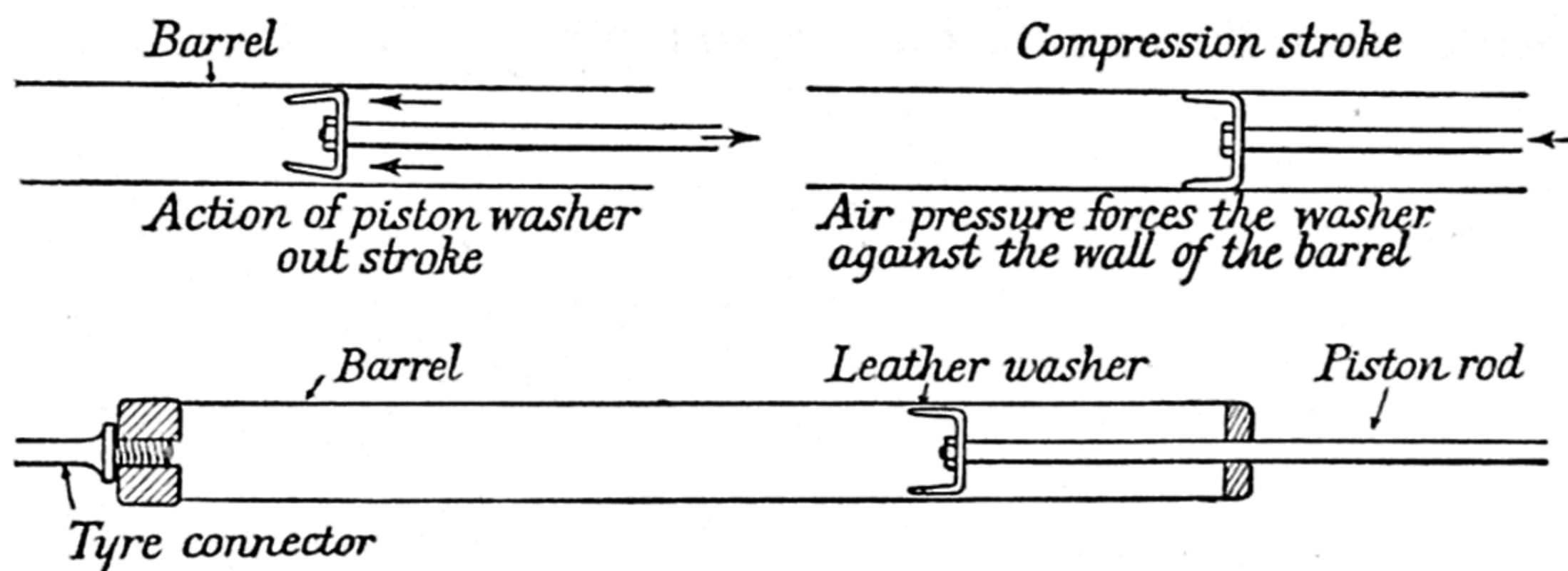


Fig. 103. — Bicycle Pump

piston. This is put on with the cup facing the outlet. As the piston is pushed in, the pressure in the barrel increases and pushes the leather washer against the wall

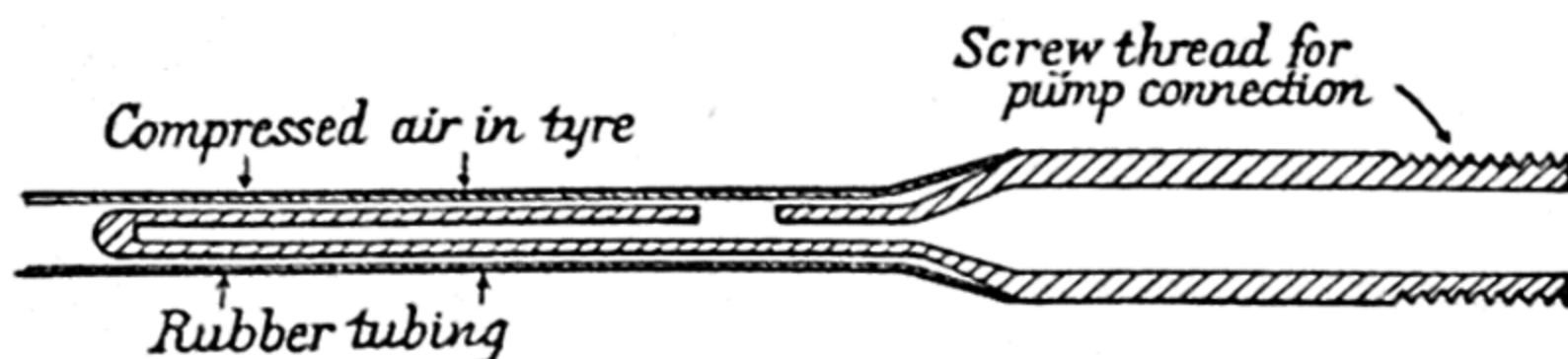


Fig. 104. — Valve on Rim of Bicycle Wheel

of the barrel so that the air cannot escape past it. When the pressure inside the barrel is greater than that in the tyre, air enters the tyre through a valve mounted on the rim of the bicycle wheel. As the piston is drawn

back, the greater pressure of the air on the inlet side enables it to push the cup-shaped washer inwards and so to enter the outlet side of the barrel.

## QUESTIONS

1. How would you show that the pressure in a column of water increases with the depth? How would you show that this pressure acts equally in all directions?

2. Explain the action of an artesian well.

3. Why is it not safe for a submarine to go down below a certain depth in the sea?

4. Why is a balloon sent up with its gas bag not fully inflated?

5. Explain carefully how you would find the pressure of the atmosphere, given a barometer tube, a dish and some mercury.

6. Describe with the aid of a diagram the principle of the construction of an aneroid barometer. Explain why it can be used to measure altitude. L.

7. Would you expect the reading of a barometer at the bottom of the shaft of a coal-mine to be the same as that at the top of the shaft? Give your reasons.

8. State Boyle's Law. How would you verify it?

9. What volume of oxygen, measured at atmospheric pressure (15 lb. per sq. in.), will escape from an oxygen cylinder when the tap is fully opened if the original pressure of the gas inside the cylinder is 150 lb. per sq. in. and the volume of the cylinder is 2 c. ft.?

10. Explain how a lift pump works. Why can it not be used if the lower valve is more than a certain distance above the surface of the water to be raised?

11. What sort of pump is used on a fire-engine and why?

12. 100 c.c. of air at 76 cm. pressure is compressed until its volume is 25 c.c. What is its new pressure? What would be its volume if the pressure was changed to 19 cm.?

13. An empty gas jar is inverted and pushed mouth downwards into water. Explain what will happen if the jar is immersed to a depth of 34 ft. below the surface.

## CHAPTER VIII

### THE DEVELOPMENT OF THE GREEN PLANT

Certain conditions are necessary before seeds can germinate. These are a favourable temperature, neither too hot nor too cold, and the presence of air and moisture. In order that seeds may continue to grow, they also require a supply of food to last until they are able to manufacture food of their own. This supply of food, as we shall see below, is stored up inside the seed itself. The majority of seeds, when they have ripened and been scattered, require a certain definite time before germination is possible, even if the conditions are otherwise favourable. This **resting period** varies with different kinds of plant. Some seeds will germinate at once, and sometimes in warm wet autumns wheat grains will germinate on the stalk before it can be harvested. In the case of most seeds scattered in the autumn, it is too cold for them to germinate by the time the resting period has elapsed, and they remain dormant throughout the winter and begin to grow when the warmer weather arrives in the spring. It is clearly an advantage that germination should not occur in the autumn, for tender seedlings are soon killed by frost, as every gardener knows, while seeds, before they have germinated, can stand very adverse conditions. Dry seeds can be kept for years without losing their power of growth, and cases have been recorded of seeds germinating after having been kept as long as fifty years.

EXPERIMENT 30. — Examine a broad bean seed, as obtained from the seed merchant. Notice how hard and slightly shrunken it appears, and find the **hilum**, or scar, where it was attached by the seed-stalk to the pod in which it ripened. Soak the bean in water for a few hours, and see how the outer skin, the seed coat or **testa**, swells up and becomes wrinkled. If the soaking is continued the rest of the seed increases in size also, so much so that the testa is stretched smooth again. Look carefully with a lens at one end of the hilum and you will see a tiny hole, the **micropyle**. Squeeze the seed and notice that a little drop of water comes out of the micropyle. It is through the micropyle that most of the water has entered the seed, although some has passed through the testa. Close to the micropyle is a ridge, under which lies the root of the new plant, which, while it is tucked away inside the seed and before it germinates, we call the **embryo**. Make a careful drawing of the seed, showing the position of the hilum, micropyle, and radicle or root.

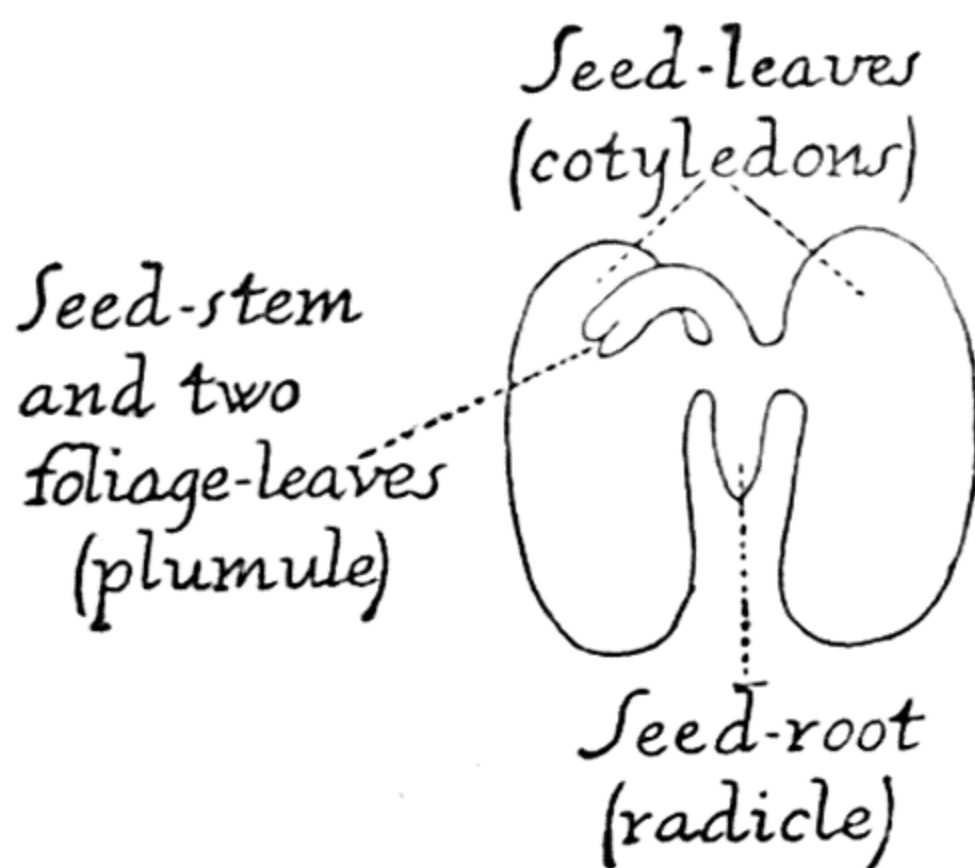


Fig. 105. — The Cotyledons of the Broad-bean separated

Now remove the testa, which comes off quite easily, and observe that the new plant consists of (1) two large seed-leaves or cotyledons, which can easily be separated, joined to the rest of the embryo by short stalks (fig. 105), (2) the **radicle** or seed root, and (3) the young shoot or **plumule**. On the inside of the testa, just by the micropyle, is a little flap that originally contained the tip of the radicle. The plumule lies in a groove in the middle of the cotyledons.

Until the young plant has grown sufficiently to produce its first green leaves it is unable to get its own food, and sufficient food is therefore stored in the seed to give the young seedling a start. In the case of the broad bean this food is stored in the thick and swollen cotyledons, and it is because seeds of beans, wheat, and many other plants have so much food stored up in them that they are so valuable as human food-stuffs.

**EXPERIMENT 31. — The conditions necessary for germination.** Take four test-tubes and a number of seeds of mustard that have been soaked in water for twenty-four hours. At the bottom of the first test-tube place some dry cotton-wool or sawdust, and add a few dry seeds. In the second and third test-tubes place damp cotton-wool and some of the soaked seeds. In the last test-tube place some soaked seeds. Add an inch or so of water that has recently been boiled to expel any dissolved air that it might contain, and then been allowed to cool. Add carefully a layer of oil on top of the water to make quite sure of preventing any air from getting to the seeds by dissolving in the water (air does not dissolve in oil). Place test-tubes 1, 2, and 4 in a warm place, e.g. near a radiator, and the third tube in the coldest possible place (if the weather is not cold the tube should be surrounded with a vessel containing water and ice). Examine the tubes each lesson for three weeks, and see which seeds germinate the best. It will be found that the seeds in test-tube 2 germinate well, but that those in the other tubes do not. The seeds which germinate have air, water, and warmth; those in test-tube 1 have no water, those in test-tube 4 no air, and those in test-tube 3 no warmth. What conditions are necessary for the germination of seeds?

**EXPERIMENT 32. — To follow the stages in the germination of seeds of (a) the broad bean and (b) mustard.** Soak a number of seeds and place them on damp sand in a warm place. See that the sand is kept moist and note each lesson the changes that have occurred. Plant other seeds in shallow soil. Make careful drawings to illustrate the changes you have observed.

### **The Germination of the Broad Bean.**

The first part of the seedling to emerge from the seed is the root, which grows downwards. Then the stalks of the cotyledons start to grow and push out from the seed the plumule, consisting of a short shoot with a bud at its end, the shoot being bent over so that the bud is downwards. The bud shoot still remains curved over until its stem has grown sufficiently to bring it above ground, when it straightens and unfolds to produce the first green leaves. The curvature of the shoot protects the very tender bud as the shoot forces

its way through the soil. Meanwhile the root has been growing rapidly and forming a number of small rootlets. Just behind the tip of each root are produced a large number of fine colourless threads called **root-hairs**. These attach themselves very closely to particles of soil, and are able to absorb water from the latter even when the particles appear to be quite dry and crumbly. It

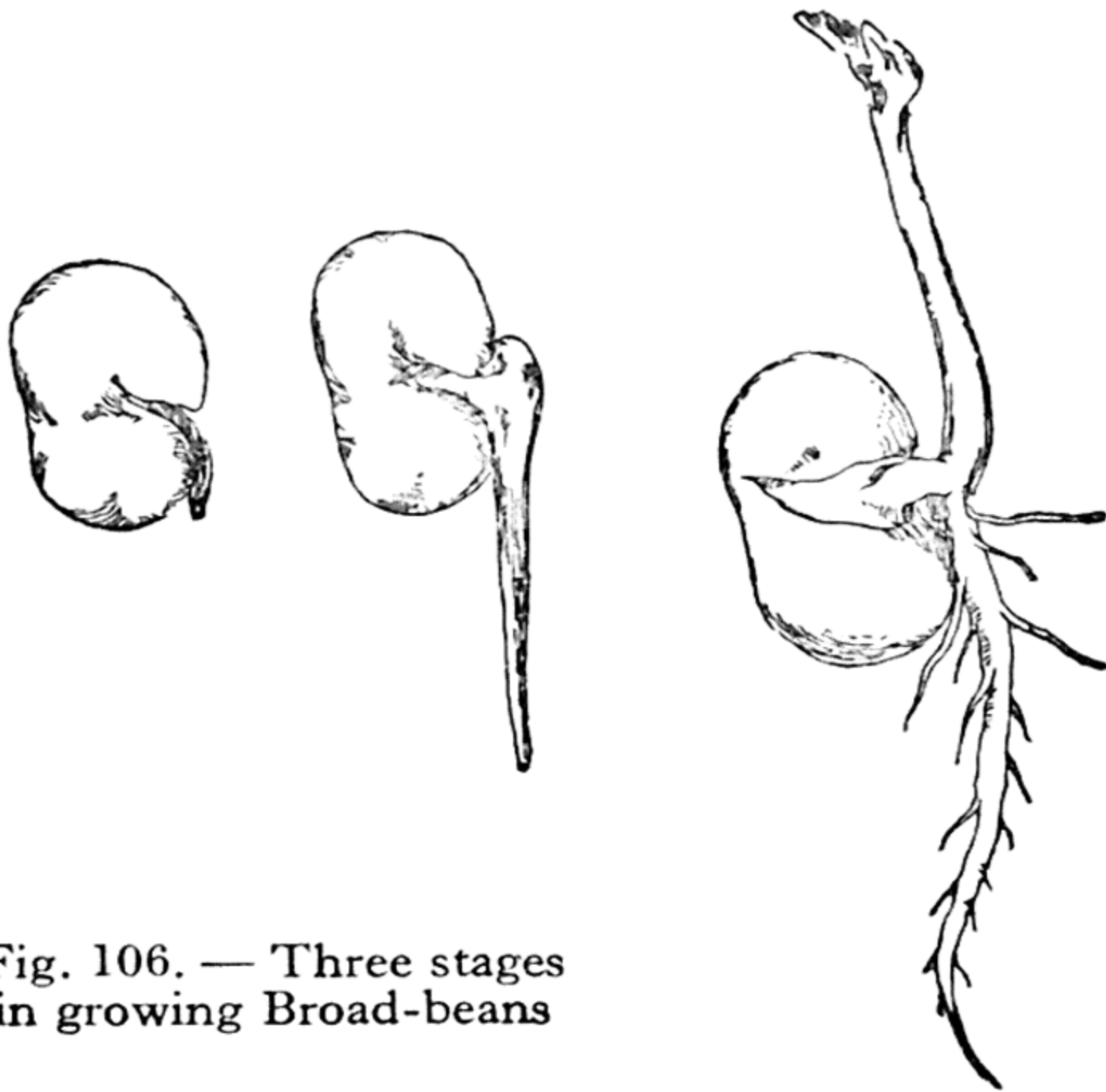


Fig. 106. — Three stages in growing Broad-beans

is through the root-hairs that roots absorb water from the soil. As the root increases in length, the older root-hairs die off and new ones are produced nearer the end of the root. The split testa and cotyledons of the bean remain below the surface of the ground, but the latter shrivel up as the food they contain is passed on to the rapidly growing seedling. The cotyledons, then, store up food for the seedling and, by the growth of their stalk, liberate the plumule from the seed.

## The Germination of Mustard.

As in the case of the bean, the radicle is the first part to grow, and it very soon forms root-hairs. But then, instead of the part of the shoot *above* the cotyledon stalks growing and carrying the plumule above ground, in this case the part of the stem between the cotyledons and the radicle grows, and grows very

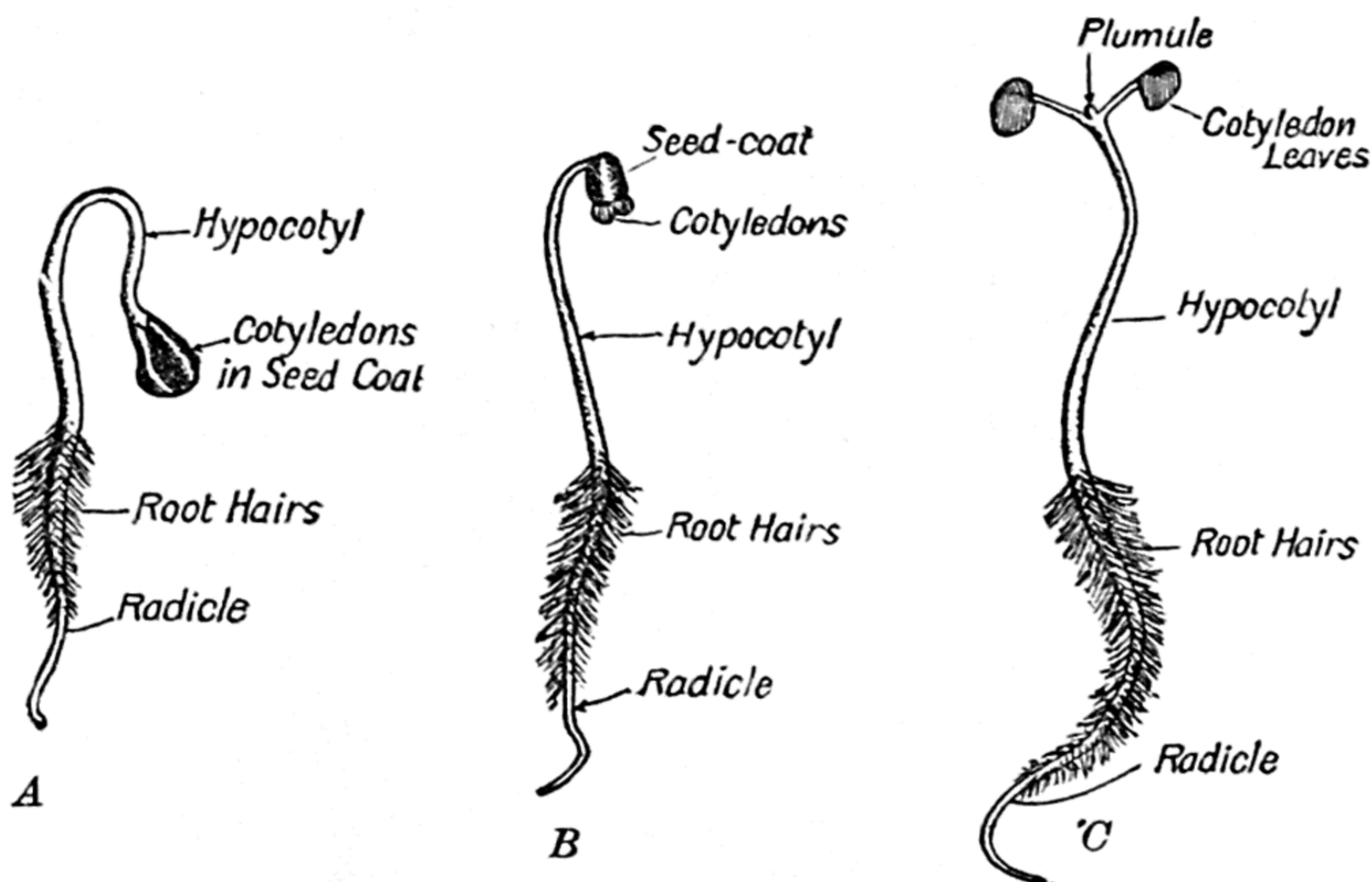


Fig. 107. — Stages in the germination of Mustard

rapidly. As a result of this the cotyledons and plumule are pushed above ground, still enclosed in the seed coat. When the cotyledons are above ground they begin to turn green, and to open out, throwing off the now useless testa. They form the first green leaves of the young plant, but are different in shape from the leaves produced later, when the plumule bud has developed further. In this case the cotyledons serve three purposes — they store up food, they protect the plumule until it is above ground, and they act as the first green leaves.

**EXPERIMENT 33. — To find where the growth of a bean seedling is most rapid.** Take a bean seedling, the root of which is about an inch long, and make equidistant marks at intervals of about one millimetre on the root and shoot with the aid of a piece of stretched thread dipped in Indian ink. Examine the seedling again after a couple of days and notice that the marks are no longer equidistant. Where are they widest apart? Where has growth been most rapid?

### **Response to Stimulus.**

If someone sticks a pin into us we jump, and probably cry out; if we are hungry and smell appetizing food, our mouths water. If we unsuspectingly catch hold of something that is too hot, we instantly let go. When we get grit in our eyes, they water. In all these examples we become aware, in one way or another, by our sense of touch or of smell, of something outside ourselves that is affecting us, and immediately we act in a certain way that is quite instinctive and unconscious. We are said to respond to a **stimulus**. The stimulus comes to us from outside and causes us to react in a certain manner. It is a characteristic of all living things that they are able to react to stimuli. Different organisms may react to different kinds of stimuli or react to the same stimulus in different ways. This power of responding to stimuli, or **irritability**, as it is called, is very important, for it enables living things to protect themselves from conditions that might injure them, and to take advantage of conditions that are favourable to them. We can illustrate this very well by experiments on seedlings. Plants have not sense organs like ours, but nevertheless they are sensitive to certain stimuli, which produce definite responses.

**EXPERIMENT 34. — To show the response of a seedling to the stimulus of light.** Select a few seedlings with straight shoots and mark the stems at equal intervals with Indian ink, as in Experiment 33. Grow the seedlings in a box fitted with a light-tight lid, and with a circular hole about two inches in diameter in the middle of one side. Place the box in a window

so that light enters it only through the hole. Examine the seedlings after several days and notice that they are all growing towards the light. Examine the marks on the stems. How has the bending towards the light been brought about? Has the bending occurred at that part of the stem which is growing most rapidly (fig. 108)?

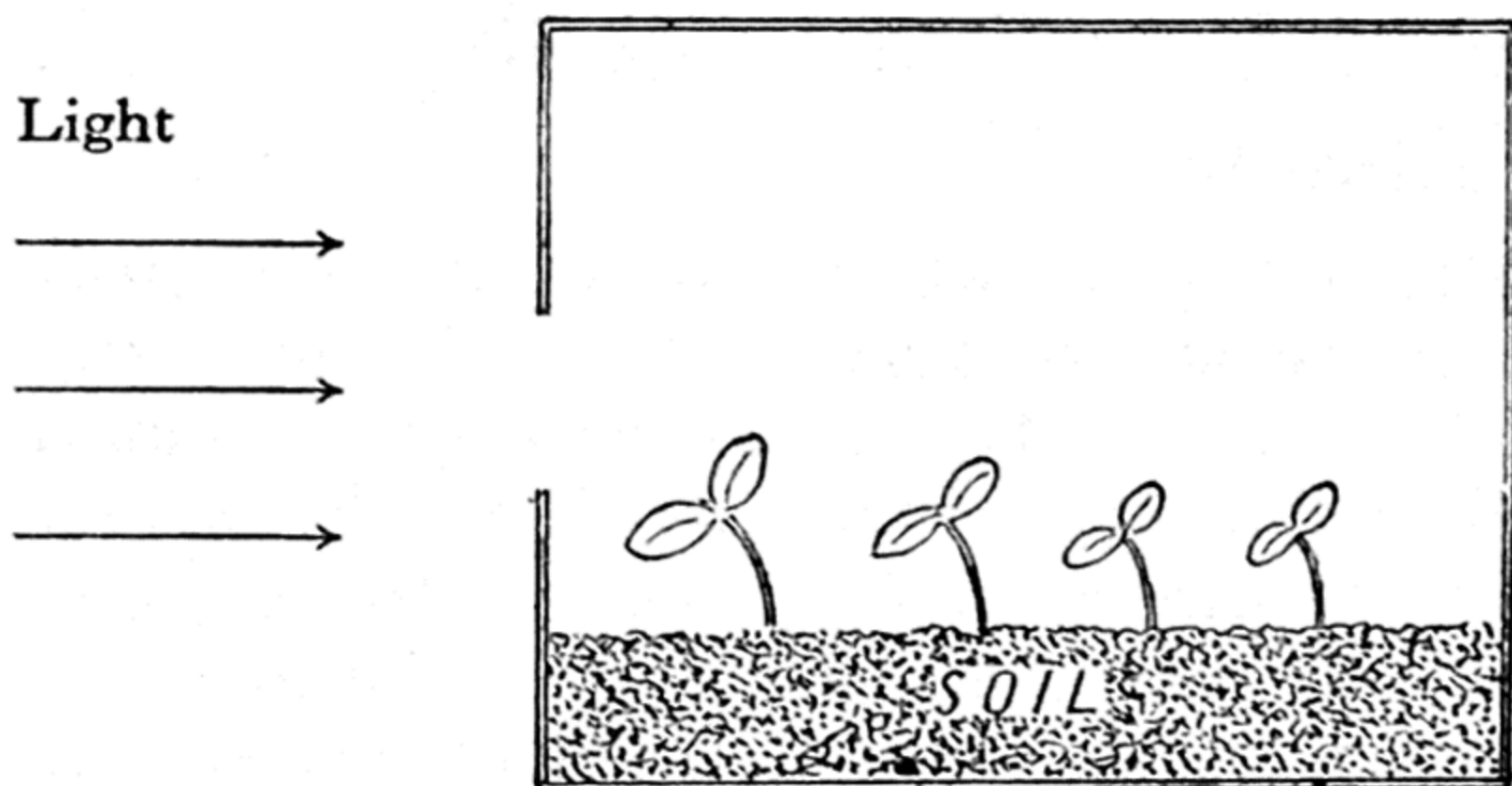


Fig. 108. — Response of seedlings to the stimulus of light

Not only seedlings but all growing plants turn their shoots towards the light. When plants are grown in pots in a window it is necessary to turn them round almost daily if a nice vertical shoot is to be obtained. This response of plant stems to the stimulus of light is clearly an advantage to the plant, for its leaves cannot fulfil their task of manufacturing food in the absence of light, and the stem, growing towards the light, brings the leaves into the light also.

The part of the shoot which is sensitive to light is the tip. This can be shown by growing a number of seedlings with the tips of their shoots covered with little tinfoil caps that shut out the light. Such seedlings will not bend towards the light. Other parts of plants also respond to the stimulus of light. Thus roots tend to grow away from the light, and leaves to set themselves at right angles to it.

**EXPERIMENT 35. — The response of a seedling to the stimulus of gravity.** Take a germinated broad bean seedling

with the root an inch or so in length. Pass a piece of thin wire through the middle of the cotyledons (this does not harm the plant), and suspend it by the wire from the cork of a bottle containing a little water, so that the seedling is in damp air. Arrange so that the radicle is in a horizontal position. Repeat with other seedlings having their roots pointing vertically upwards and vertically downwards. Leave all the seedlings in the dark so that they will not be affected by light. Examine them again in a day or two and observe that the root which was originally growing downwards continues to grow in the same direction, and that the other two roots have bent over

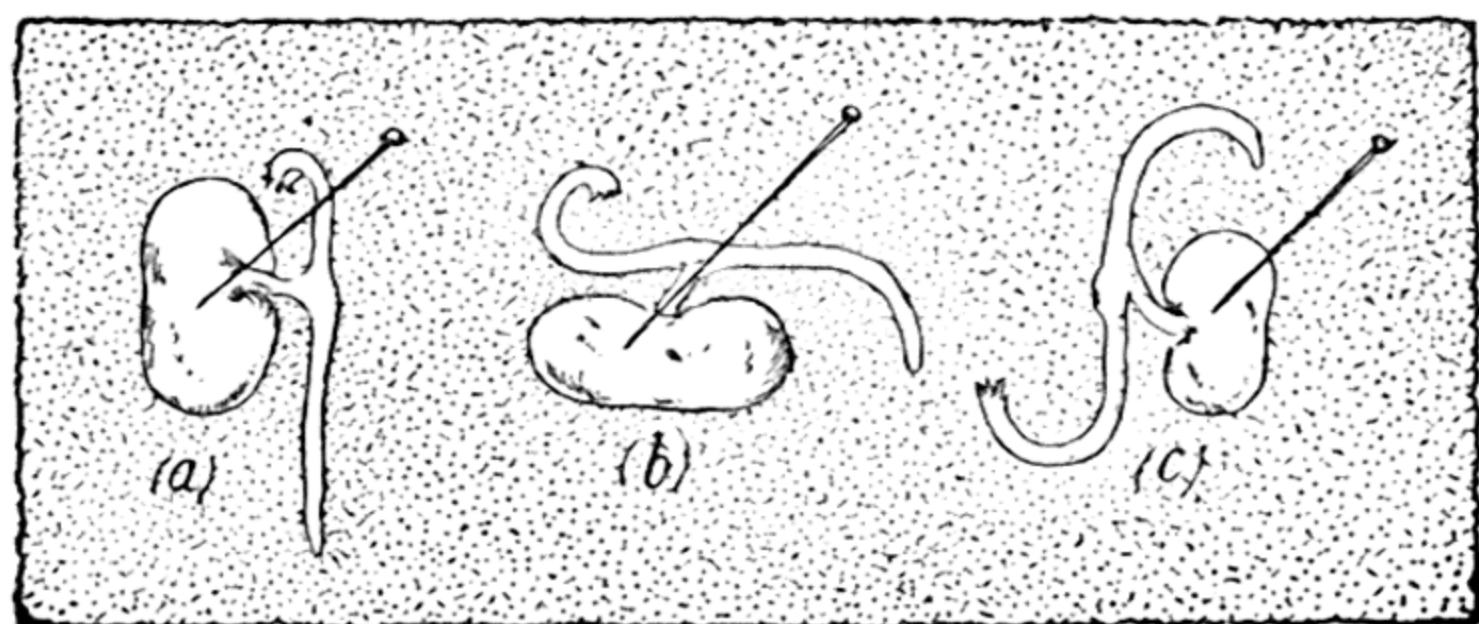


Fig. 109. — Response of seedlings to the stimulus of gravity

so that the tip of the root is downwards. Where has the curvature occurred? Repeat the experiment with seedlings from which the tips of the roots ( $\frac{1}{10}$  in.) have been removed. Is the result the same? What part of the root is sensitive to the stimulus of gravity (fig. 109)?

The roots of plants, as we have seen, always start to grow downwards as they emerge from the seed, and this happens no matter in what position the seed may lie as it germinates. So long as the root-tip is not damaged this downward tendency of roots persists and, if they are moved, they will bend so as to grow downwards again. This is true only of main roots. Secondary or branch roots often grow nearly horizontally. That this downward growth of roots is a real living response to the force of gravity, and not due merely to the weight of the root, is shown by the fact that a horizontal root whose root-tip has been removed continues to grow

horizontally despite its weight. The shoot of a plant also responds to gravity, but in the opposite direction — it grows upwards. This can easily be shown by placing on its side a pot containing a plant, and leaving it in the dark. After a few days the stem is found to have bent upwards.

Just as by turning a window plant round at intervals we can prevent it growing to one side under the stimulus of light, so by turning a root round so that gravity acts on it in every direction in turn, we can prevent the stimulus of gravity from causing the root to bend downwards, and in a similar manner, we can prevent a shoot from bending upwards. To avoid the inconvenience of continually turning the plant round, an apparatus called a **klinostat** is used which does this mechanically (fig. 110).

**EXPERIMENT 36. — To show that roots respond to the stimulus of water.** Plant a number of bean seedlings in damp moss in a fairly large-meshed sieve, and hang the sieve up so that its underside is visible. The roots of the seedlings grow downwards through the meshes of the sieve but, instead of continuing to grow downwards, they turn upwards again and grow along the underside of the moss or even back into it. Since one of the main duties of roots is to absorb water it is obviously an advantage to a plant that the stimulus due to the presence of water should be stronger than the stimulus of gravity. In most cases, of course, a root would be more likely to find a sufficient supply of water by growing downwards.

## Tropisms.

Various parts of plants respond to certain stimuli such as light and gravity, and respond by growing in a certain direction depending on the direction of the stimulus. Such responses are called **tropisms**. The response to the stimulus of light is called **heliotropism**, that to gravity **geotropism**, and that to water **hydro-tropism**. The stem of a plant, which grows *towards* the light, is said to be positively heliotropic, while the

root, which grows away from the light, is negatively heliotropic. Similarly, the roots of plants are positively, and the shoots of plants negatively, geotropic.

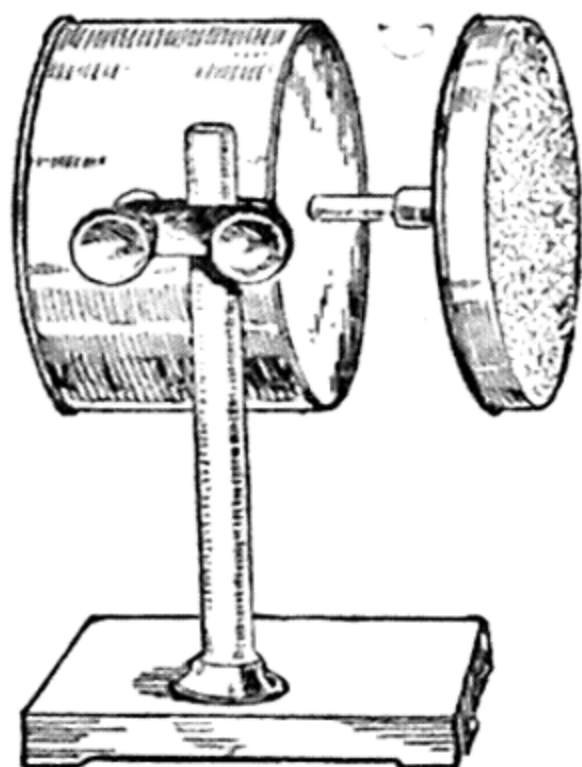


Fig. 110. — Klinostat

Seedlings can be pinned on to the cork mat on the right, which is rotated by the clockwork mechanism on the left.



Fig. 111. — Seedlings of Bean of the same age: A, grown in the light; B, in the dark.

## Etiolation.

Light also produces certain other effects on plants. Thus it reduces the rate at which shoots grow. Seedlings grown in the dark form long straggling stems, and leaves smaller than the normal and yellowish in colour instead of green (fig. 111). Such plants are said to be **etiolated**. The yellowish colour of the leaves is due to the fact that chlorophyll, the green colouring matter normally found in leaves, is not formed in the absence of light. Without chlorophyll, plants are unable to manufacture food, so that when the supply of food

originally present in an etiolated plant is exhausted the plant dies. If part of a grass lawn is covered for two or three days, the part covered turns yellowish but, provided it has not been killed by prolonged deprivation of light, soon regains its former colour when the cover is removed.

**EXPERIMENT 37. — To find the effect of absence of light on the growth of bean seedlings.** (a) Plant two or three soaked beans in a box of soil and keep them in a dark place. Compare from time to time the seedlings grown in this way with others planted at the same time but grown in a window-box. What differences do you notice? (b) Divide thirty broad bean seeds into three groups of ten. Weigh the first group, put it in a porcelain evaporating dish, and heat on a sand bath, being careful, however, not to cause any charring. During the heating the seeds decrease in weight, because water contained within them is driven off. Allow the seeds to cool and weigh them again. In order to make sure that all the water has been driven off, heat them once more and see if there is any further loss in weight. If there is, heating and weighing must be continued until two consecutive weighings are the same. Dividing this weight by 10, we get the dry weight *a* of one seed. Why did we take *ten* seeds in each group?

Soak the other seeds in water and plant them in moist soil. Grow one of the groups of ten seeds in the light and the other group in a dark cupboard. A week or two after the seedlings grown in the light have produced green leaves, carefully remove both sets of seedlings from the soil, wash their roots free from adhering particles, place each set of seedlings separately in a large porcelain dish, and dry them on a sand bath as above. Find by weighing the average dry weight *b* of the seedlings grown in the light and that of the etiolated seedlings grown in the dark, *c*. It will be found that *c* is *less* than *a*, while *b* is *greater* than *a*. The seedlings grown in the light have been able to make their own food after the formation of green leaves, but the etiolated seedlings have not, and their dry weight is less than that of the original seeds, since they have used up in their growth the supply of food originally stored in the seeds.

When celery is about a foot high, soil is packed round the stem up to the level of the lowest leaves, or brown

paper is tied round the stems, as a result of which the white and etiolated stem thus obtained is rendered less tough and more palatable.

QUESTIONS

1. What conditions are necessary for the germination of a seed? How would you show that they were necessary?
2. Why is it unnecessary to plant a seed in any particular position?
3. Describe a typical bean seed. Explain what happens when the seed germinates. C.W.B.
4. What differences are there between the ways in which the broad bean and the mustard germinate?
5. What is meant by *irritability*? Describe experiments to show the irritability of plants to various stimuli.
6. In what ways does light affect a growing seedling?

## CHAPTER IX

### THE DEVELOPMENT OF THE FROG

Frogs are usually to be found in cool moist spaces, such as rich meadows, but at the breeding season they make their way to slow-moving shallow streams and shallow pools of water. Here we may see them in the spring, the more active males, and the sluggish-moving females swollen with the load of eggs inside them. When the female frog is ready to lay her eggs the male frog will jump on her back and clasp her closely with his fore limbs locked under hers. They will remain paired in this way for several days, with just their heads above the surface of the water. Meanwhile the female frog will have laid between 1000 and 2000 eggs, one at a time, from an opening between the legs called the **cloaca**. The eggs, however, will not grow unless they have first been fertilized by male cells or sperms. This fertilization is effected by the male frog. The latter, so situated that his cloaca is very close to that of the female, liberates his fertilizing sperms upon the eggs as they are laid.

Frogs' eggs, when they are laid, are about  $\frac{1}{10}$  of an inch in diameter, and black in colour, with a thin layer of transparent jelly around them. Being heavier than water, they sink to the bottom. The tiny sperms soon burrow their way into the eggs and fertilize them, and after a time the transparent jelly swells up so that each egg is nearly half an inch in diameter. At this stage the eggs are lighter than water, and float on the surface in large masses called spawn, stuck together by their jelly.

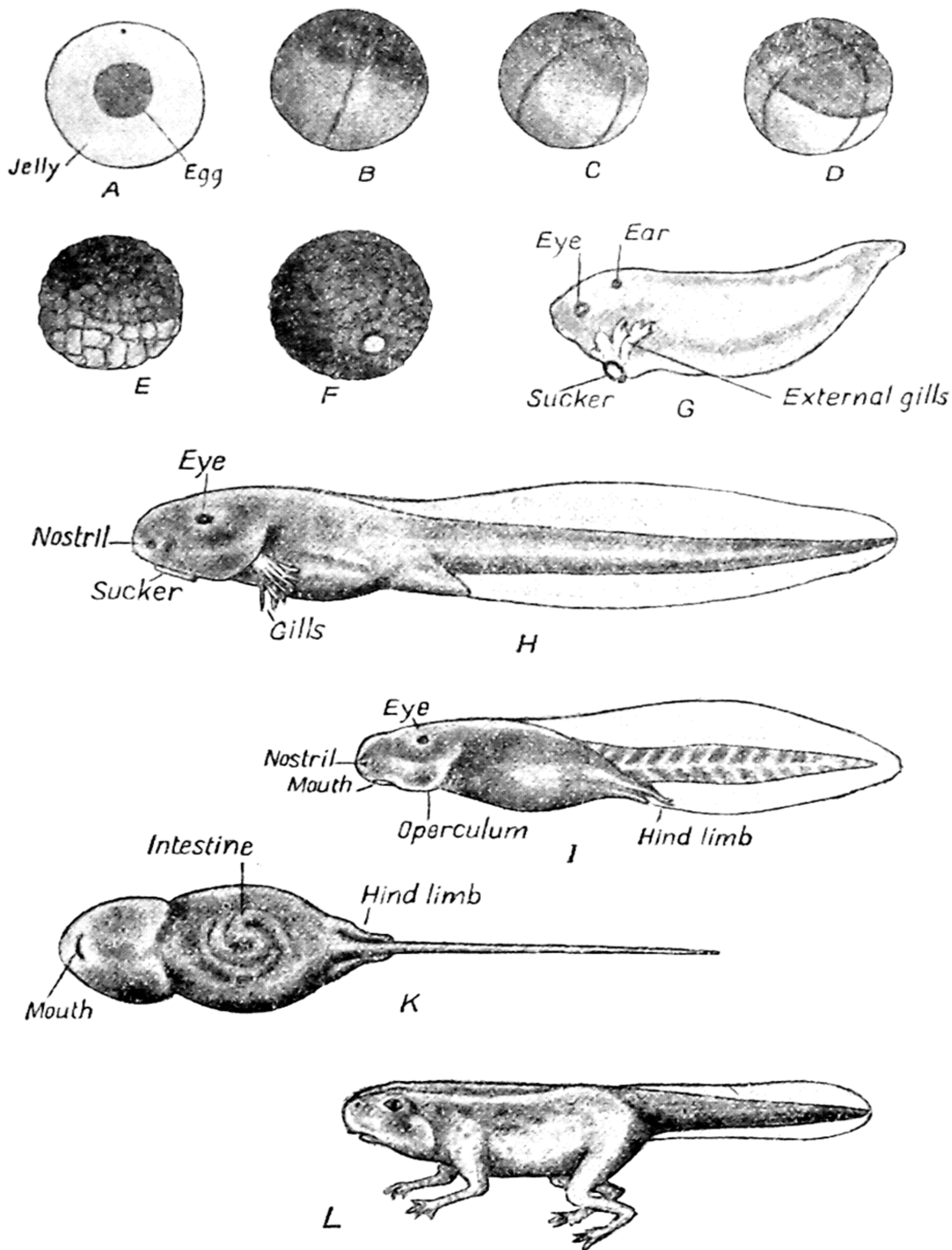


Fig. 112. — Frog Development

A, Egg. B-F, Stages in segmentation of egg. G, Newly hatched tadpole. H, Stage with external gills fully formed. (Drawn on a larger scale than other views.) I, External gills have disappeared. K, View of I from the underside to show the coiling of the intestine. L, Metamorphosis nearly complete.

At first the upper half of the spherical egg is dark in colour and the under half white, the latter consisting of **yolk**, which acts as food for the growing organism. Soon, however, the upper portion grows round the lower and hides the yolk. On examination with a lens, it is possible to see grooves or segments in the egg. This stage is called **segmentation**. Further changes occur and the dark central mass becomes first two-lobed and then three-lobed, and soon can be seen the beginning of the head, body, and tail of a young tadpole, curled up in the centre of the jelly. After about a fortnight the jelly becomes more fluid, and the young tadpole is able to break through it by its own movements and become free. The jelly, having completed its task of protecting the developing tadpole, now rots away.

The young tadpole as it escapes from the egg has a crescent-shaped gland (sometimes called a sucker) on the head that produces a sticky substance by means of which the tadpole attaches itself to water-weed. The young tadpole still has no mouth, but for a day or two longer it continues to grow by using up the remains of the yolk inside its body. Its tail gets longer and more powerful, the crescent-shaped gland begins to disappear and a mouth forms with horny lips. At this stage the tadpole is able to see, and moves about, feeding on tiny plants floating in the water. When it first emerges from the egg it has two pairs of feathery **external gills**, by means of which it is able to breathe air dissolved in water, in the same way as fishes do. Later a third pair of gills branch out from the back of the head, but meanwhile **internal gills** have been forming and taking over the task of extracting dissolved air from the water. Eventually the external gills disappear. Water is now able to pass through the mouth, over the internal gills, and out through an opening on the left side of the body called the **spout**.

For some weeks the tadpole continues to feed and

grow, but all the time it is changing internally. After about six weeks **hind limbs** begin to appear at the junction of the body and tail, and a fortnight later the **fore limbs** can be seen. The right limb makes its way out through the right **gill cover** and the left limb through the spout. Already **lungs** are developing inside the tadpole, and it now makes frequent visits to the surface to take in air, all the more necessary since the development of the fore limbs is interfering with the working of the gills. After ten weeks the outer skin is shed, including the horny jaws, and the tadpole begins to seek animal food. The greater part of the food required for these changes, however, is derived from its own tail, which begins to shorten and be absorbed. This becomes very noticeable about the eleventh week, and after another week the young frog is ready to come out of the water and begin its life on land. Its gills have disappeared, its hind limbs have lengthened and many other changes have taken place as well.

The young frog continues to grow for another two or three years, at the end of which time it is fully mature and capable of laying eggs, if a female, or, if a male, of fertilizing them. It usually lives for several years longer as an adult. During the winter frogs hibernate in the mud at the bottom of pools. Here, with mouth and nostrils closed, they remain in a deep sleep, scarcely breathing, and getting through their skin what little air they need from air dissolved in water.

### **Metamorphosis.**

If we did not know that the tadpole and the frog were different stages in the life of the same organism, we should probably never suspect it, for both tadpole and frog are able to feed and grow, and they seem so totally different. The change by which the fully-grown tadpole develops into a frog is called **metamorphosis**. Metamorphosis occurs in many other organisms besides

the frog, and the form that changes into the adult form is called a **larva**. The tadpole, then, is the larva of the frog.

### **The Adult Frog.**

An adult frog is about 3 in. long, and has a smooth, moist skin, usually green and brown in colour on the back and yellowish underneath. It has no neck, the head being attached directly to the body, and no tail. The two eyes are large and prominent, so placed that the frog can see upwards as well as forwards and sideways. The upper and lower eyelids are almost incapable of movement, but there is a third transparent eyelid which moves right across the eye. A frog has no external ears, but behind and slightly below the eyes there are two circular patches of skin which cover the entrance to the internal ears. The frog is able to hear well, not only on land, but also under water.

The fore limbs of the frog are comparatively short, and have only four digits compared to our five, the missing one corresponding to our thumb. In the male frog, the first finger is slightly swollen, especially at mating time, to form the pad that helps the frog to grip the female during the mating process. The hind legs are long and very powerful, and by suddenly straightening them the frog is able to hop two or three feet, landing on the fore limbs to break its fall. Each of the hind legs has five long toes, which are **webbed**, that is, they have flaps of skin joining the toes together. The frog is an excellent swimmer, normally using only his powerful hind limbs to propel him, and folding the fore limbs across his body.

On the front of the head are two holes, which are the entrances to the nostrils. A frog breathes by means of its lungs, but it is also able to breathe air through its skin, provided the latter is moist. This is one of the reasons why frogs live in cool damp surroundings.

Frogs live mainly on insects, but they will also eat small worms and caterpillars. They are therefore very useful to man in keeping down pests that damage his crops and flowers. Frogs lie in wait for their prey, and when an unwary insect is within its reach the frog suddenly shoots out its sticky tongue around the insect, flicks the latter back into its mouth, and immediately swallows

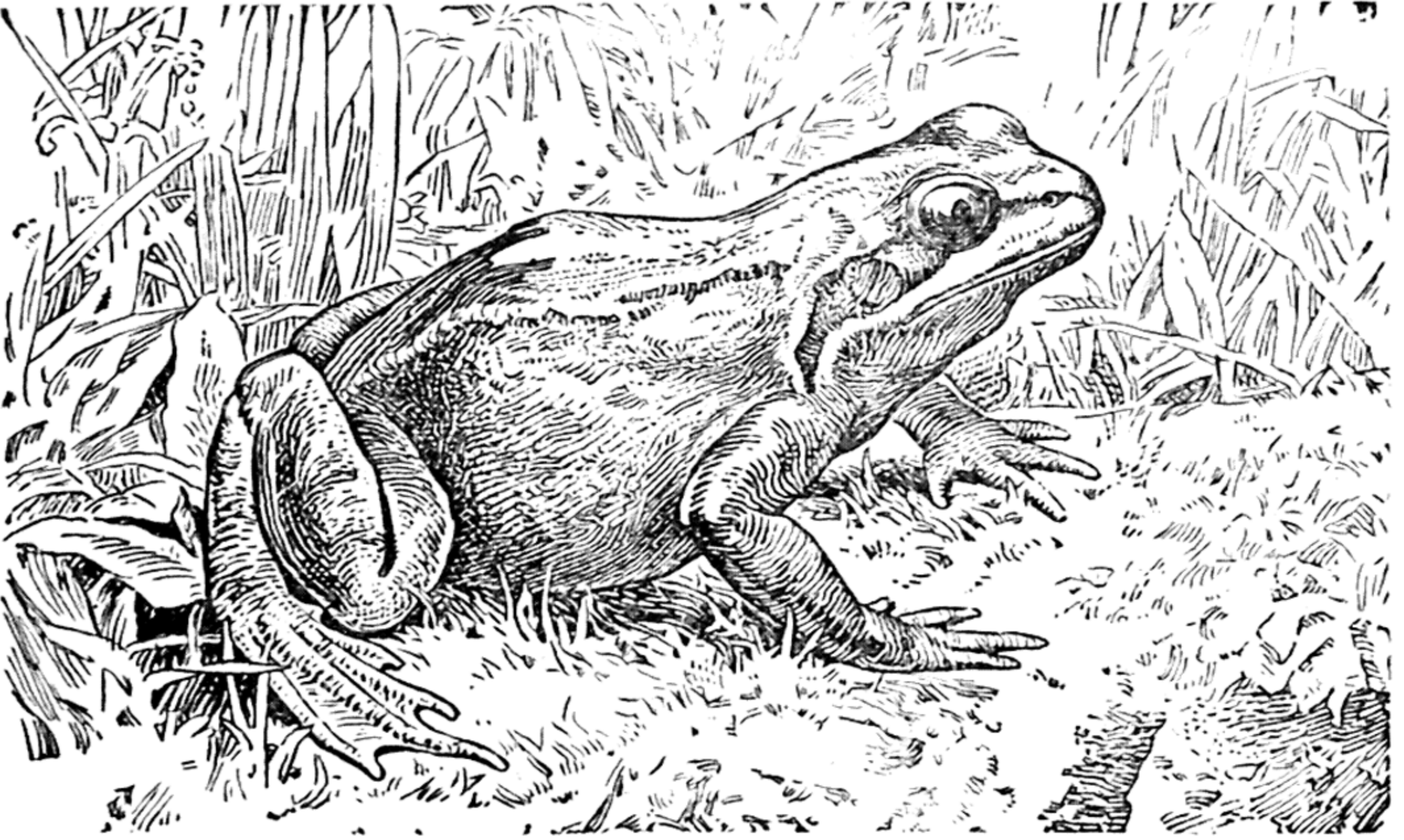


Fig. 113. — Adult Frog

it. A frog's tongue is about an inch long and, unlike ours, is fixed at the *front*, the free end being folded over towards the throat. This enables the whole of its length to reach out for an insect. When a frog is swallowing, its eyeballs move inwards and downwards, and by their pressure help to force the still living prey down the gullet into the stomach. Frogs do not chew their food. Although they have no teeth in the lower jaw, they have a number of small teeth, all alike, in the upper jaw, and also in the roof of the mouth, but these are used only for holding their prey and preventing its escape.

We have already seen that of the thousands of seeds produced by a plant only a very few ever produce fully-grown plants. The vast majority of them perish. A single pair of frogs will produce nearly 2000 eggs in a season, and yet the number of frogs does not seem to increase. Evidently similar mishaps befall the great majority of frog eggs before they have developed into mature frogs. Most of the casualties occur in the tadpole stage, for tadpoles form the main food of many pond animals in spring, and they are also eaten by certain birds. The eggs, before they have hatched out, are fairly safe provided their pool does not dry up, for it is almost impossible to detach one egg from a mass of spawn owing to the sticky nature of the jelly, and the whole mass is too large to be swallowed at a single gulp. The frog itself is preyed upon by grass snakes and certain kinds of birds, as well as by some of the larger fishes. Its main defence lies in its **protective coloration**, which makes it very difficult to see against its usual background. The colour of a frog depends to some extent on the background in which it is living, and varies from almost black to nearly yellow. A frog transferred from a dark environment to one with a light background, or vice versa, is able to change its colour in the course of a few hours. At the approach of danger a frog will remain motionless, hoping not to be noticed, and then, if it gets a chance, it will suddenly hop into long grass or into water.

The frog leads the first part of its life in water, breathing through gills like a fish, and the latter part on land, breathing through lungs, although it usually keeps fairly close to water. It belongs to a class of organisms called **Amphibia**, a kind of link between fishes, living wholly in water, and animals, living wholly on dry land. Other members of the same class include toads, newts, and salamanders.

QUESTIONS

1. Why do frogs prefer to live in cool damp places? Why is it an advantage for them to be able to change the colour of their skin?
2. Describe the process of reproduction in the frog.
3. What do frogs feed on and how do they catch their prey? Do you think frogs are useful or harmful to man? Give your reasons.
4. Describe the changes that take place in a tadpole from the time it emerges from the egg until it has completely changed into a frog.
5. What do you understand by the terms *larva*, *metamorphosis*, *amphibian*?

## CHAPTER X

### WATER, SOLUTION, CRYSTALS

Water is essential to all forms of life, which die if they are unable to obtain it. We never realize how essential water is until we find ourselves deprived of it. We all know how plants droop and wither during a long spell of dry weather, and how quickly they recover if the rain comes in time. Animals die of thirst if they are unable to obtain water for several days. The presence of this life-giving fluid is all that is responsible for the remarkable contrast between a fertile oasis and the barren sandy wastes around it.

Water occurs in nature in many forms — as rain-water, spring-water, river-water, sea-water, as cloud and mist, and as ice and snow. The difference between these various forms, other than that due to temperature, depends on the presence or absence of other substances dissolved in them. Water is a **solvent** and will dissolve many substances, which are said to be **soluble** in water. Because of its great solvent power no naturally-occurring water is entirely free from small quantities of other substances in solution. All naturally-occurring waters contain dissolved air. Rain-water is practically free from dissolved solids, at any rate in the country, although in the neighbourhood of towns it may contain solid matter dissolved from soot and smoke. Ordinary tap water contains both air and solids.

**EXPERIMENT 38. — To show the presence of (a) air and (b) solids dissolved in tap water.**

(a) Take a beaker of water and heat it over a gauze. Soon a large number of tiny bubbles will be seen adhering to the surface of the vessel. These bubbles are not steam, for the temperature of the water is far below its boiling-point. They consist of air, originally dissolved in the water and now driven off on heating.

(b) Put 5 c.c. of tap water on a watch-glass and place the latter on top of a beaker containing water kept boiling by means of a bunsen. Continue to boil the water in the beaker until the whole of the liquid on the watch-glass has evaporated. There will be a small quantity of a white chalky residue. The "harder" the water the greater will be the amount of residue.

From the second part of Experiment 38 we see that when water containing dissolved solids is boiled the solids are left behind. In order to obtain pure water, free from dissolved solids, we have only to condense the steam that is driven off. Water obtained in this way is called **distilled water** and is used in large quantities in chemical laboratories because of its purity. It is also employed for "topping up" the acid in accumulators.

**EXPERIMENT 39. — To prepare some distilled water.** Fit up the apparatus shown in fig. 114. A flask is fitted with a cork through which passes a shorter bent tube, connected to a condenser. This consists of a straight glass tube surrounded for the greater part of its length by a wider tube through which can be passed a stream of cold water. Water from the tap is led in at the lower side tube and allowed to run to waste from the upper one. Place in the flask 200 c.c. of tap water in which have been dissolved a few crystals of potassium permanganate. This gives an intense purple-coloured solution. Now boil the liquid in the flask and at the same time pass cold water through the condenser. The steam passes down the inner tube and is condensed, running out of the lower end in the form of drops. The whole process is called distillation. Do not boil the water in the flask too rapidly or all the steam may not be condensed before it reaches the end of the condenser. Notice that the water which has flowed through the condenser is distinctly

warmer than that entering. Why is this? Examine the distillate that has been condensed. It is quite free from any purple colour due to permanganate. Evaporate 5 c.c. to dryness on a watch-glass, as in Experiment 38(b), and note that there is no residue. Taste the distillate — it tastes flat and insipid.

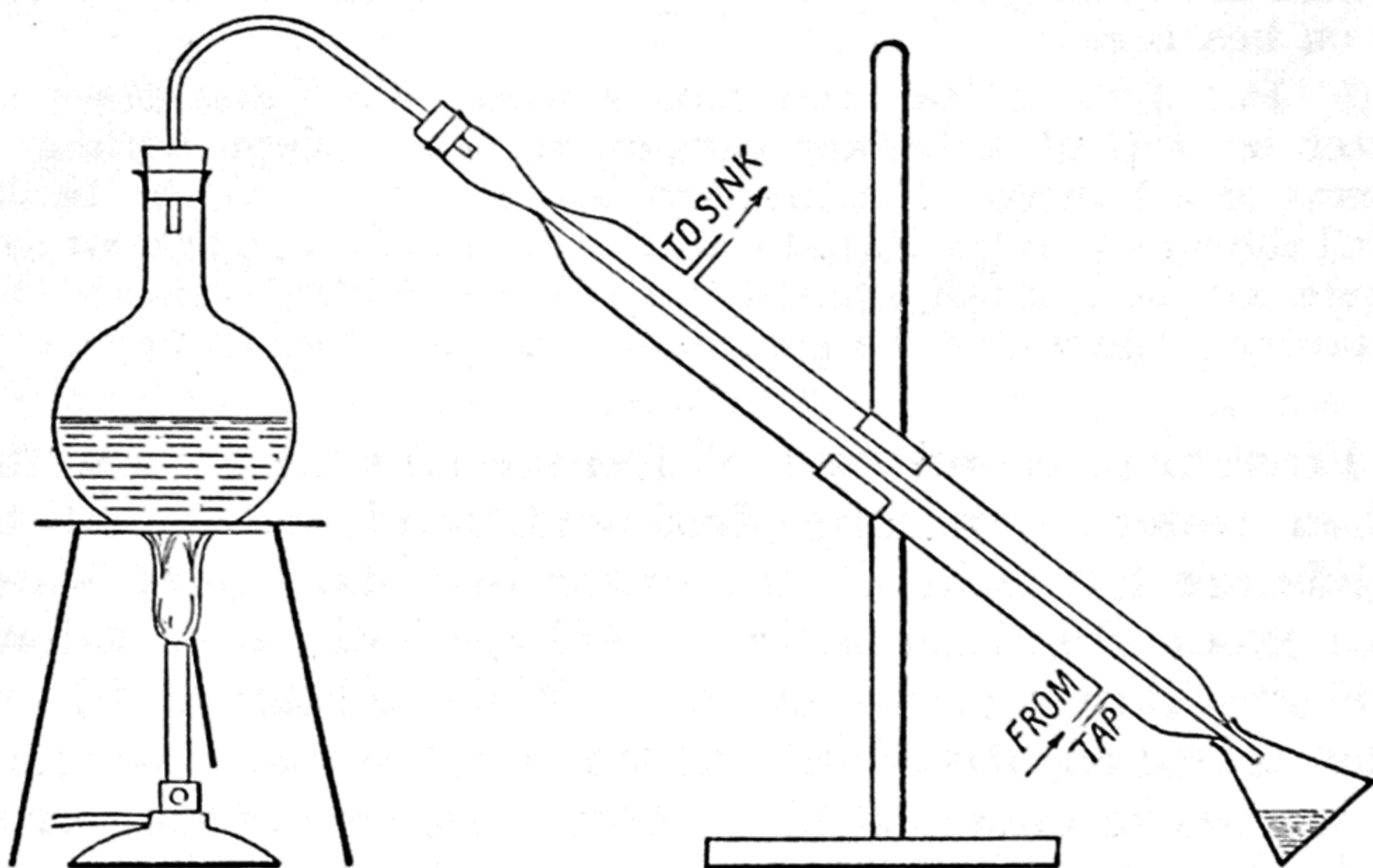


Fig. 114. — Distillation of Water

Running water especially, and other forms of natural water as well, such as lake and sea-water, contain varying amounts of insoluble matter suspended in them. Such suspended matter is in the form of fine particles, so small that they settle to the bottom and form a sediment only very slowly. This sediment may consist of tiny particles of earth and soil, animal and vegetable debris, and the minute living cells of bacteria ("germs"). While such a suspension will gradually deposit the larger particles on standing, it is necessary to filter in order to remove the smaller ones. River-water is usually very muddy in time of flood, as the water is flowing rapidly and so is able to hold in suspension much larger particles than normally.

**EXPERIMENT 40. — To remove suspended matter from water.** Shake up a little soil with some tap water. A thick muddy liquid results. Allow it to stand for some minutes and observe that the larger and coarser particles fall to the bottom. The upper layer, however, although much clearer than before, is still cloudy and brown in colour. To filter the liquid put a

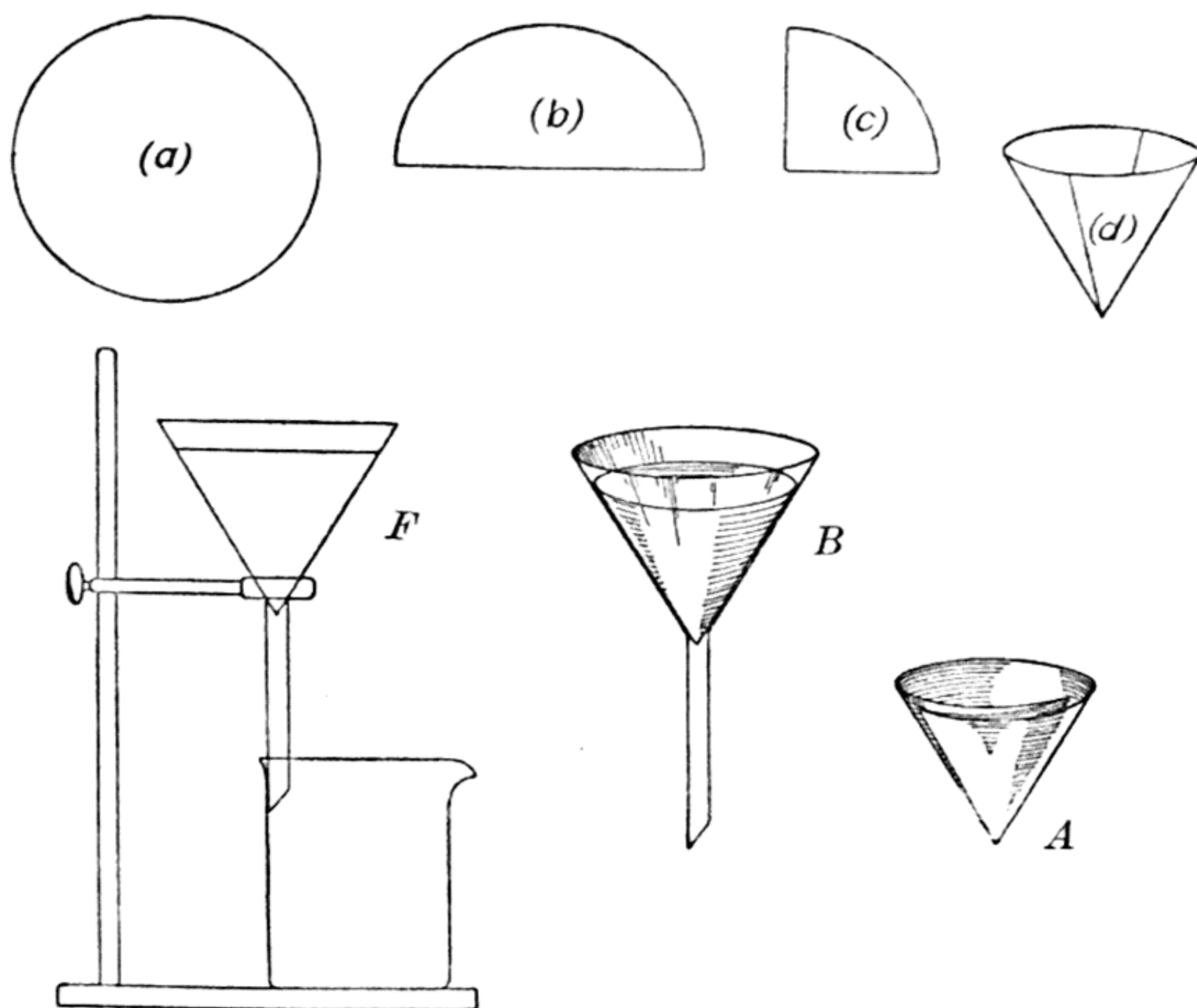


Fig. 115. — Filtration Apparatus

The filter paper (a) is folded in two along a diameter (b), then into two again (c), and is finally opened out to form a cone (d) and A, which fits into the glass funnel as in B. F shows the funnel fixed in the filter stand.

glass filter funnel in a ring attached to a burette stand and place a folded filter paper in the funnel (fig. 115). Wet the filter paper with a little water so that it will stick to the side of the funnel. Now run the liquid down a length of glass rod on to the filter paper, taking care to see that the level of the liquid does not rise above the top of the paper. The clear colourless liquid which passes through the fine pores in the filter paper is called the filtrate. Note the solid matter left behind on the filter paper.

A chemist will sometimes describe a substance as "pure". By this he means that the substance contains nothing else mixed with it. Thus, distilled water is pure water, for it contains none of the gases or solids found in ordinary water. But when we use the term "pure" in connection with food or with drinking water we do not mean quite the same thing. All that we mean then is that the food or water is quite free from anything harmful.

### **River-water.**

River-water is water that has drained from the land and contains dissolved solids, which vary with the nature of the soil and rocks found in the district, together with animal and vegetable debris. Especially in the neighbourhood of towns much refuse and sewage finds its way into rivers and it is dangerous to drink such water on account of the germs it contains.

### **Spring-water and Deep Well-water.**

These are very similar. They contain dissolved solids, but most of the germs and suspended matter have usually been filtered off as the water passed down through porous rocks such as sandstone, limestone, and chalk.

### **Sea-water.**

Rivers are constantly bringing down dissolved substances to the sea, in which these solids accumulate. The surface water of the ocean evaporates and, carried by the winds over the land, condenses and falls as rain, but the solids are left behind in the ocean. The ocean, therefore, is very slowly but steadily growing more salty. Sea-water contains on an average about 3.6 per cent of dissolved solids, of which common salt forms the bulk (2.6 per cent). Sometimes inland seas dry up, depositing layers of common salt and other substances

that they once held in solution. A lake or sea that is drying up contains a much higher percentage of solids than ordinary sea-water, and the Dead Sea at its southern end, which is farthest from the inlet of the River Jordan and where evaporation is greatest, contains an amount of dissolved solid sufficient to give the surface water a specific gravity of 1.25.

### Mineral Waters.

Sometimes the water of a particular spring contains dissolved substances not usually found in spring-water. Water from such a spring is called a **mineral water**. The actual quantity of solids present may be quite small, sometimes even smaller than in ordinary spring-water. Many of these waters have medicinal properties. The springs of Buxton and Tunbridge Wells contain iron; those at Bath and Harrogate contain sulphur; at Epsom the mineral water contains magnesium sulphate (Epsom salt), at Marienbad and Carlsbad, sodium sulphate (Glauber's salt), at Vichy, bicarbonate of soda, and so on. In a number of cases the springs are hot, as at Bath ( $120^{\circ}$  F.) and Buxton ( $82^{\circ}$  F.). Such waters have come from great depths, where the temperature is higher than it is at the surface of the earth.

Mineral waters such as Vichy and Apollinaris are bottled and exported for use as table waters. These and others are also imitated by dissolving a suitable quantity of the appropriate substances in ordinary water, and the term "mineral water" has been extended in every-day speech to include a variety of sweetened and effervescing drinks familiar to every schoolboy.

### Solubility.

Gases dissolved in water can be expelled by heating, but most substances are more soluble in hot water than in cold. The solubility of a substance in water at a given temperature is defined as **the weight of solid that**

**will dissolve in 100 grams of water at the temperature under consideration.** When a solution contains so much of a given substance that it is no longer able to dissolve any more it is said to be **saturated**. A solution that is saturated with, say, salt is still able to dissolve another substance such as sugar. Within certain limits each substance dissolves independently.

**EXPERIMENT 41. — To determine the solubility of nitre in water at the temperature of the room.** Take about 50 c.c. of distilled water and add 20 gm. of nitre. Heat the mixture in order that the nitre may dissolve more rapidly. Allow the solution to cool down to the temperature of the room. The proportion of nitre taken is more than sufficient to saturate the water in the cold, so that some of the nitre crystallizes out. When the temperature of the solution is steady pour off about 10 c.c. of the clear upper part of the solution into a weighed evaporating dish and weigh again. The difference between these two weighings will give the weight of the solution taken. Now evaporate the solution to dryness on a water-bath and when the solid residue is quite dry weigh the evaporating dish again, being careful first to wipe it dry on the underside. The difference between the first and third weighings gives the weight of nitre contained in the solution evaporated.

Suppose the weight of the evaporating dish was  $a$  gm., of the dish and solution  $b$  gm., and of the dish and residue  $c$  gm.

Then weight of solution taken  $= b - a$  gm.

and weight of residue  $= c - a$  gm.

therefore, weight of water  $= (b - a) - (c - a)$  gm.  
 $= b - c$  gm.

i.e.  $(b - c)$  gm. of water at room temperature will dissolve  
 $(c - a)$  gm. of nitre.

therefore 100 gm. of water at room temperature will dissolve

$$(c - a) \times \frac{100}{(b - c)} \text{ gm. of nitre.}$$

**EXPERIMENT 42. — To find how the solubility of potassium chlorate varies with the temperature.** Take a number of test-tubes and put 10 c.c. ( $= 10$  gm.) of water in

each from a pipette. To the first test-tube add 1 gm. of potassium chlorate, to the next  $1\frac{1}{2}$  gm., to the next 2 gm., and so on up to 5 gm. Warm each test-tube until the solid has dissolved, but avoid boiling away any of the water. When all the solid has dissolved place a Centigrade thermometer in each test-tube and use it as a stirrer to keep the temperature of the solution uniform as it slowly cools down. As the temperature falls, the amount of potassium chlorate the water in a given tube can hold diminishes, so that a temperature is reached at which the water can only just hold in solution the quantity that is actually present in the tube. On the slightest further fall in temperature the solution has to let go some of the dissolved solid which appears as fine flaky crystals showing a beautiful iridescent glitter when held up to the light. Note the temperature for each tube at which this first occurs. Naturally the tube containing the largest amount of solid will be the one in which crystals form at the highest temperature. Suppose this temperature is  $90^{\circ}$  C. Then at  $90^{\circ}$  C. 10 gm. of water can just dissolve 5 gm. of potassium chlorate, the solubility of which therefore is 50 gm. (i.e. the weight dissolved by 100 gm. of water) at  $90^{\circ}$  C. From your results construct a table showing the solubility of potassium chlorate at different temperatures, and use it to draw a graph showing the connection between solubility and temperature for this substance (see fig. 116). Such a graph is called a solubility curve.

The solubility curves for a few common substances are shown in fig. 116. It will be seen that while some substances are much more soluble in hot water than they are in cold, the solubility of common salt changes very little with increase in temperature.

**EXPERIMENT 43. — To find whether writing chalk is soluble in water.** Grind a stick of writing chalk to a fine powder in a mortar and put the powdered chalk (which is not the same substance as ordinary chalk) in a beaker. Add 50 c.c. of distilled water and boil for a few minutes to give the chalk every opportunity of dissolving. Filter off any undissolved chalk and evaporate a few c.c. of the clear filtrate to dryness on a watch-glass over a beaker of boiling water. Is there any residue? If so, could it have come from the distilled water? How could you verify your opinion about this? What conclusion do you draw from your experiment as to the solubility of writing chalk in water?

Water is not the only solvent, or liquid capable of dissolving solids. There are innumerable others, such as alcohol (methylated spirits), ether, benzene, petrol, etc. Many substances that will not dissolve in water are readily soluble in one or more of the other solvents and, on the other hand, many substances soluble in

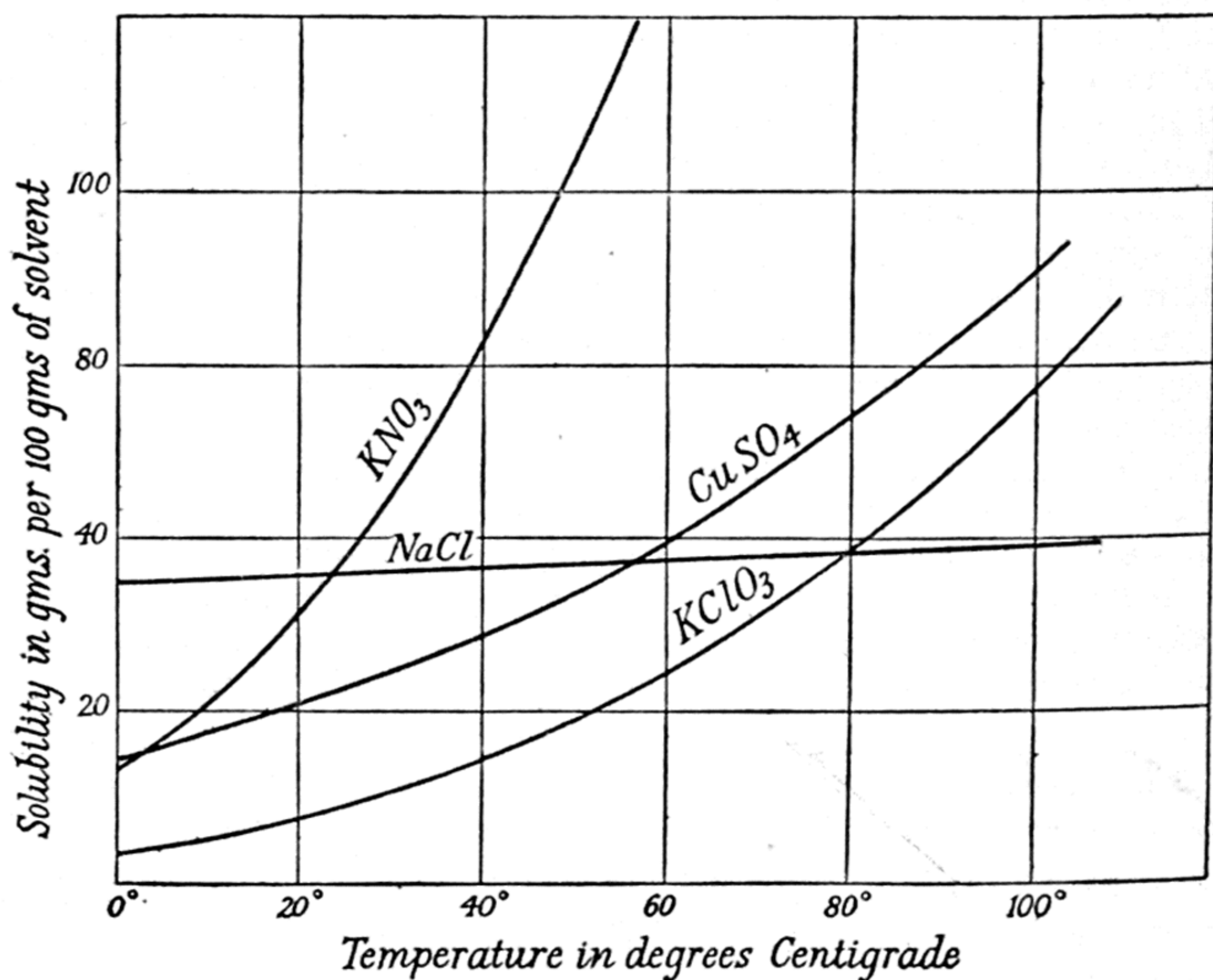


Fig. 116. — Solubility Curves of some common substances

water are not soluble in other solvents. Fats and grease, while not soluble in water, dissolve easily in petrol and other solvents; that is why these liquids are used to remove grease stains from clothing. Unfortunately many solvents, besides evaporating rapidly, are highly inflammable, and so very dangerous to use. As in the case of water, the solubility of substances in these solvents is greater the higher the temperature of the solvent.

**EXPERIMENT 44. — To compare the solubilities of iodine in water and alcohol.** Take two small crystals of iodine of about the same size and put one in a test-tube containing 10 c.c. of water, and the other in a tube containing 12.5 c.c. (i.e. 10 gm., since the density of alcohol is 0.8 gm./c.c.) of alcohol. Shake the tubes up for a minute or two. In which liquid is the iodine more soluble? How can you tell?

We have seen that when a solid dissolves in a liquid the solid is not destroyed. We can get it back again by evaporating off the liquid. Furthermore, the weight of the solution is equal to that of the solvent plus the weight of the dissolved solid.

**EXPERIMENT 45. — To show that there is no loss of weight when a solid dissolves.** Place on the right-hand pan of a balance a beaker containing some water and a glass rod. Put a watch-glass containing some sugar on top of the beaker and counterpoise the balance. Lower the beam and pour the sugar from the watch-glass into the water in the beaker, stirring it round with the glass rod. Replace the watch-glass on top of the beaker. The sugar dissolves, but on raising the beam of the balance the total weight in the right-hand pan is found not to have altered.

## ✓ Crystals.

Examine some large crystals of sugar, alum, copper sulphate, and other substances. The first thing that strikes one about them is the similarity of shape between the crystals of the same substance. If we look more carefully we shall see that all the crystals of a given substance are not quite similar. All have the same number of edges and faces similarly arranged, but the length of the sides are not always in the same proportion. The fact to which they owe their similarity is that the corresponding faces and edges always meet at the same angle in crystals of the same substance. Thus the faces of the crystals of common salt meet at right angles. The faces of a crystal are smooth and flat, and when the crystal is broken by a sharp blow it breaks

up into pieces which also have smooth plane faces. This is called **cleavage**, and is particularly well shown by crystals of Iceland spar.

Crystals not only have a regular shape on the outside, they have also a definite internal structure and behave differently towards heat, light, and electricity when these pass through them in different directions. When crystals increase in size the new material deposited is laid down in a regular manner and in such a way that the angles between the faces are unaltered.

Crystals can be obtained in several ways. We have already seen that when a hot saturated solution cools down the excess of dissolved solid crystallises out. This is **crystallization by cooling**. If we make a saturated solution at room temperature and set it aside in an open dish the liquid will gradually evaporate. Since this solution is already saturated, the water that evaporates must deposit the solid it contained. The more slowly crystals are formed the larger they grow, so that those obtained in this way, **by evaporation**, are larger than those obtained by cooling. Such crystals, however, are generally imperfect owing to their being crowded together at the bottom of the vessel and owing to the fact that no fresh material can be deposited on the faces on which they rest. Some substances, such as iodine and carbolic acid, sublime readily, that is, pass directly from the solid state to a vapour without first liquefying. Such vapours will usually condense in a cooler part of the vessel to give large and well-formed **crystals by sublimation**. Finally, many solids which have been heated until they have melted will crystallize if they are allowed to cool again. This is **crystallization from fusion**, and is the way in which crystals of quartz and other minerals have been formed in the depths of the earth. Several metals, including zinc, will crystallize in this way if allowed to cool slowly from the liquid state.

Substances have their own special shape of crystal by means of which they can in many cases be easily recognized. If we make a solution containing, say, common salt and nitre and allow it to crystallize we obtain two sets of crystals, because the particles of common salt cannot help to build up crystals of nitre and vice versa — neither fits into the pattern of the other. But there are pairs and groups of substances which have exactly the same crystalline form, and when we crystallize out a mixed solution of such a pair or group we get only one kind of crystal, consisting of not one substance only but of as many as are present in the solution. If we take a crystal of chrome alum, which is purple in colour, and place it in a solution of potash alum, the crystal will continue to grow, the potash alum forming a colourless layer or **overgrowth** over the original chrome alum. Substances that have the same crystalline form and give **mixed crystals** and overgrowths with each other are said to be **isomorphous** (Gr. *isos*, equal, *morphe*, shape). Isomorphous substances usually have a similar chemical composition.

Some substances form crystals of one kind under one set of conditions and of a different kind under another set of conditions. Such substances are said to be **dimorphic** or **polymorphic** according to the number of different shapes assumed. Substances like glass, which does not form crystals when it solidifies but a hard shapeless mass, are said to be **amorphous** (*a*, without). Amorphous substances do not show the property of cleavage. Even glass, however, crystallizes very slowly, and this **devitrification**, when it occurs, renders the glass useless for subsequent glass-blowing.

**EXPERIMENT 46. — Crystallization by cooling.** Prepare in separate test-tubes warm concentrated solutions of (i) nitre, (ii) potassium bichromate, (iii) sodium nitrate. Allow the solutions to cool down to 25° C., and then transfer to fresh test-tubes which will then contain sufficient of the solid to

saturate the liquid at  $25^{\circ}\text{C}$ . These solutions will crystallize out at a convenient rate on further cooling. Place a drop of each solution on a microscope slide and watch it crystallize. Do not use too high a power; a two-inch objective is quite sufficient. If a micro-projector is available the crystallization can be shown to a whole class at once.

**EXPERIMENT 47. — To obtain a supersaturated solution.** Dissolve 50 gm. of hydrated sodium sulphate in 50 c.c. of water by warming, and pour the solution into a clean beaker. Place a watch-glass on top of the beaker to prevent particles of dust, etc., from the air falling into the solution, and allow the liquid to cool. When it is cold add a small crystal of the hydrated sodium sulphate, and notice the rapid crystallization that takes place immediately, and also the fact that the solution warms up.

**EXPERIMENT 48. — Crystallization by evaporation.** Prepare a saturated solution of copper sulphate. When it is cool transfer the clear liquid to another dish and set it aside for a few days.

**EXPERIMENT 49. — To grow a large well-formed crystal.** Prepare some small crystals of alum or copper sulphate by allowing a hot saturated solution to cool and then pouring off the remaining liquid. Select a well-shaped crystal and attach it by means of a short piece of cotton to a glass rod. Place the glass rod across the top of a beaker in such a way that the crystal is suspended in a cold saturated solution of the corresponding substance. Set aside for some days.

**EXPERIMENT 50. — To obtain an overgrowth.** Grow a crystal of chrome alum (coloured) as in Experiment 49 above, and then transfer the crystal to a saturated solution of potash alum (colourless) and leave for a few days.

**EXPERIMENT 51. — To show that fresh material is added to a crystal in a regular manner.** Break a piece of Iceland spar so as to obtain a fragment with a perfectly clean inside surface. Place this with forceps on a microscope slide and drop on to it a drop of a solution of sodium nitrate (isomorphous with Iceland spar), saturated at  $25^{\circ}\text{C}$ ., and note under the microscope how the crystals of the nitrate are deposited on the Iceland spar in a very regular manner. A few irregularly arranged crystals will also be seen. These have formed on the surface of the drop and have fallen on to the fragment of Iceland spar.

**EXPERIMENT 52. — To illustrate the dimorphism of**

**sulphur.** Shake up some flowers of sulphur with carbon disulphide (note: this substance is very inflammable). Filter through a paper, not previously wetted with water, on to a watch-glass and set aside in a fume chamber. After a few minutes the carbon disulphide will have evaporated and quite large crystals will be found on the watch-glass. These crystals, called **rhombic sulphur**, resemble two pyramids base to base and with their vertices cut off.

Dissolve a little flowers of sulphur in hot turpentine and set aside to cool. Long needle-like and almost colourless crystals of **monoclinic sulphur** form. Sulphur forms monoclinic crystals when it crystallizes out at a temperature above  $95^{\circ}\text{C}$ .

**EXPERIMENT 53. — To find the effect of heat on crystals of copper sulphate.**

Put a pipe-clay triangle on a tripod (fig. 117) and place in the triangle a dry crucible containing some crystals of copper sulphate. Heat the crucible by means of a bunsen, at first very gently and gradually more strongly. What happens to the crystals? Allow the greyish powdery residue to cool. When it is cold add a drop or two of water and notice that the powder immediately turns blue. Water is the only substance known that will do this, so that this powder, called anhydrous copper sulphate,

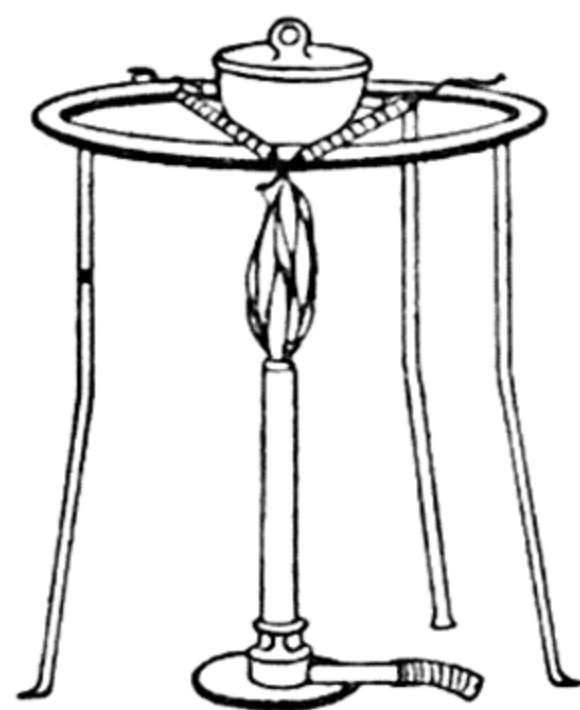


Fig. 117. — Crucible and Tripod

can be used as a test for water.

## Water of Crystallization.

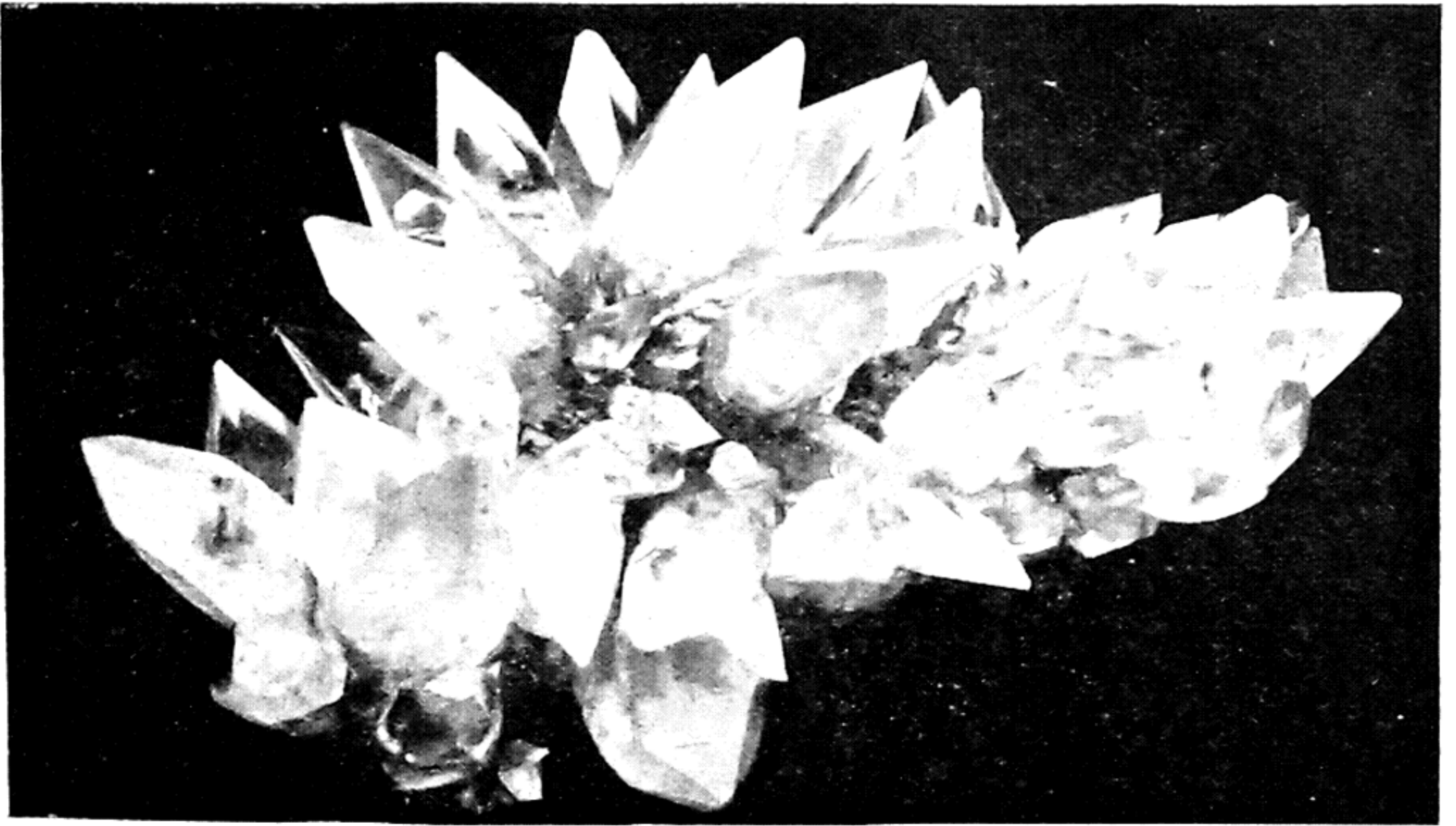
Many crystals contain a certain amount of water which is essential for their formation. Thus when copper sulphate crystals are heated and the water they contain is driven off, the crystals crumble to a greyish powder, which only regains the crystalline form on the addition of water. Crystals containing water are said to be **hydrated** and the water is called **water of crystallization**. The residue left when water of crystallization has been driven off is called the **anhydrous** substance. Crystals vary greatly in the proportion of water which they contain, but this proportion is always

the same for the same kind of crystal. Washing soda (hydrated sodium carbonate) contains as much as 63 per cent of water, and copper sulphate crystals 36 per cent.

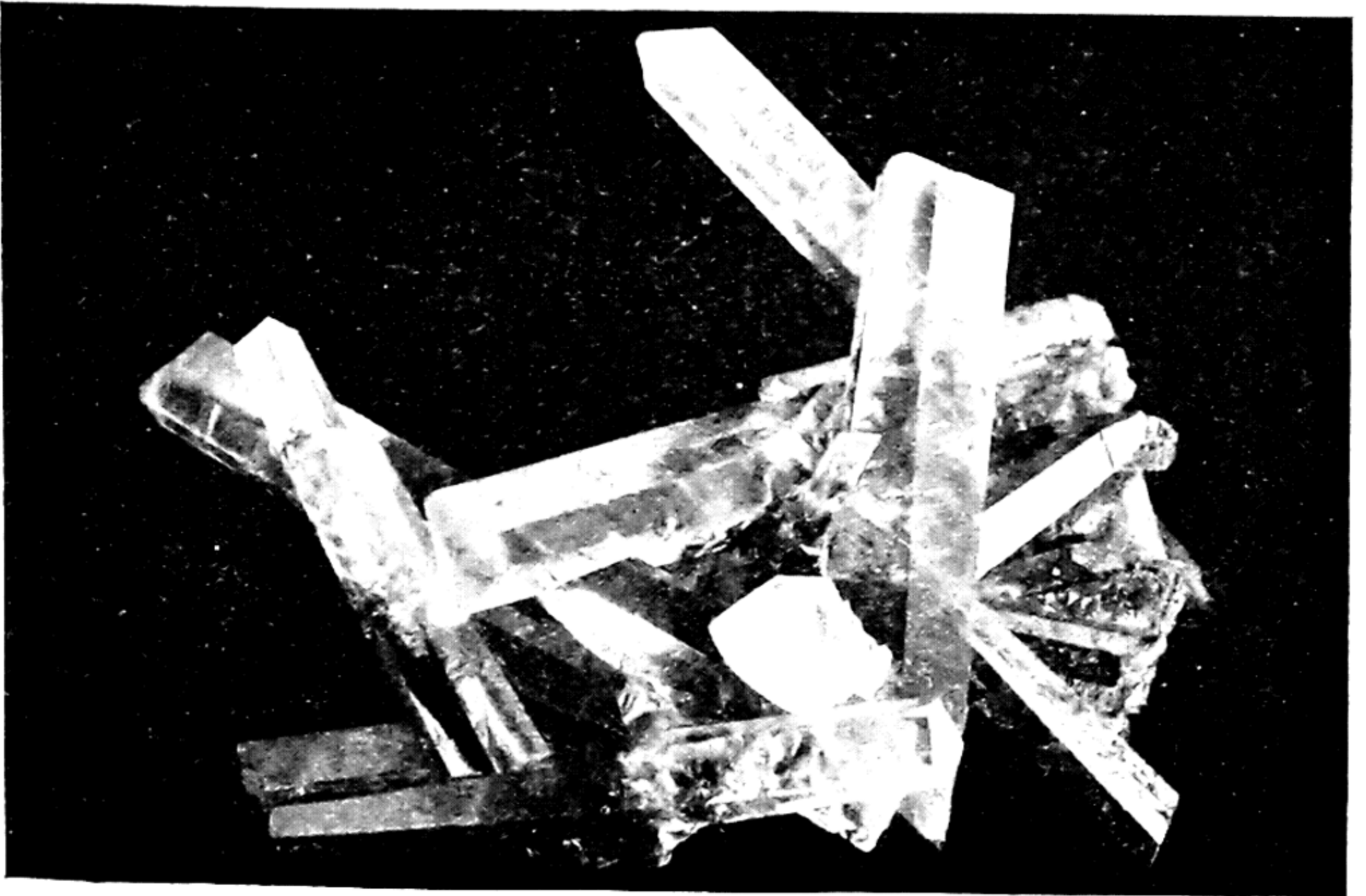
Crystals also vary greatly in the degree of firmness with which the water is held. When crystals of washing soda or of Glauber's salt are left exposed to the air they soon lose most of their water of crystallization and crumble to a powder. Such substances are said to be **efflorescent**. On the other hand, many anhydrous substances are able to absorb moisture from damp air. A good many fine powders do the same, as do also the fibres used in the manufacture of clothes. The "airing" of apparently dry clothes in a warm place drives off most of this moisture. All substances that can absorb moisture from the air without appearing damp are said to be **hygroscopic**. Some substances that are very soluble in water, such as calcium chloride and potassium carbonate, absorb so much moisture that they dissolve in it to form a solution. These substances are **deliquescent**.

✓ **EXPERIMENT 54.** — Leave out in the laboratory on open watch-glasses (*a*) crystals of copper sulphate; (*b*) anhydrous copper sulphate; (*c*) anhydrous calcium chloride; (*d*) hydrated sodium sulphate; (*e*) zinc chloride; (*f*) potassium sulphate; (*g*) Glauber's salt; (*h*) washing soda crystals. Examine again after two or three days and note down any changes that you observe. Which of these substances are (i) hygroscopic, (ii) deliquescent, (iii) efflorescent?

**EXPERIMENT 55.** — **To find the percentage of water in copper sulphate crystals.** Weigh a clean dry crucible, place in it about 2 gm. of copper sulphate crystals and weigh again. Heat the crucible, very carefully at first, as in Experiment 53, and then more strongly until all the crystals have crumbled to a grey powder. Allow the crucible to cool and weigh it again. How can we make sure that we have driven off all the water? Heat again for two or three minutes, then allow to cool and weigh once more. . What conclusion can we draw if the last weight is the same as the previous one? What ought we to do if it is not? From your results calculate the percentage of water in copper sulphate crystals.



Dogtooth Spar



Calcite

*(British Museum)*

SOME CRYSTALLINE MINERALS

(Both from the Bigrig Mine, Egremont, Cumberland)

[illegible]

QUESTIONS

1. In what respects does a crystalline substance such as Iceland spar differ from a non-crystalline one such as glass?
2. In what ways are crystals formed? Explain how you would grow a large crystal of copper sulphate.
3. Explain the terms *solvent*, *solution*, *suspension*, *saturated*.
4. Why is absolutely pure water never found in nature? What substances are found in mineral waters? Why do certain towns owe some of their importance to mineral springs?
5. Explain what is meant by a *solubility curve*. How would you determine the solubility curve for common salt?
6. 36 gm. of common salt and 80 gm. of potassium chlorate are dissolved in 100 gm. of water at 100° C. What will happen when the solution is cooled down to 150° C.? (Refer to the solubility curve given in fig. 116 for the solubilities of salt and potassium chlorate at these two temperatures.) What difference would there be if the water had been saturated at 100° C. with these two salts?
7. What do you mean by *water of crystallization*? How would you find the percentage of water of crystallization in some given crystals?
8. A solution of sodium carbonate is required. Which is cheaper for making such a solution, pure hydrated sodium carbonate (63 per cent water of crystallization) at 4*d.* per lb. or pure anhydrous sodium carbonate at 9*d.* per lb.?
9. What do you understand by the terms *hygroscopic*, *deliquescent*, *efflorescent*? Give one example of each type of substance.

## CHAPTER XI

### SOME SIMPLE ORGANISMS

#### **Amœba.**

There are many different kinds of amœba, which is a very tiny and very simple animal, so small as to be only just visible to the naked eye. About a quarter of a millimetre in diameter, it looks like a tiny speck of jelly. Different forms may be found growing in the mud of fresh-water streams, in the sea, and on damp earth. Some kinds live even in the intestine, or bowel, of man, and cause a form of the dangerous disease known as dysentery. The jelly-like material of which amœba is composed is called **protoplasm**.

Under a microscope, the shape of amœba is seen to be very irregular. The outer layer of protoplasm, called the **ectoplasm**, is stiffer and more transparent than the remainder or **endoplasm**, which contains many fine granules. Near the centre will be found a spherical body called the **nucleus**. This will not be seen very clearly in a living amœba, but shows up distinctly in a dead specimen that has been "stained" by treating it with a suitable dyestuff, as the nucleus takes up the colour much more than does the rest of the protoplasm.

Amœba is able to move about slowly and does so in a very strange way. First of all it pushes out a temporarily projecting portion of protoplasm, called a **pseudopodium**. Should the pseudopodium encounter anything harmful, it is withdrawn; if not, the remainder of the protoplasm will slowly flow after it and in this

way the amœba is able to glide over solid bodies. It changes its direction by putting out its pseudopodia from some other side. It follows that, as the organism

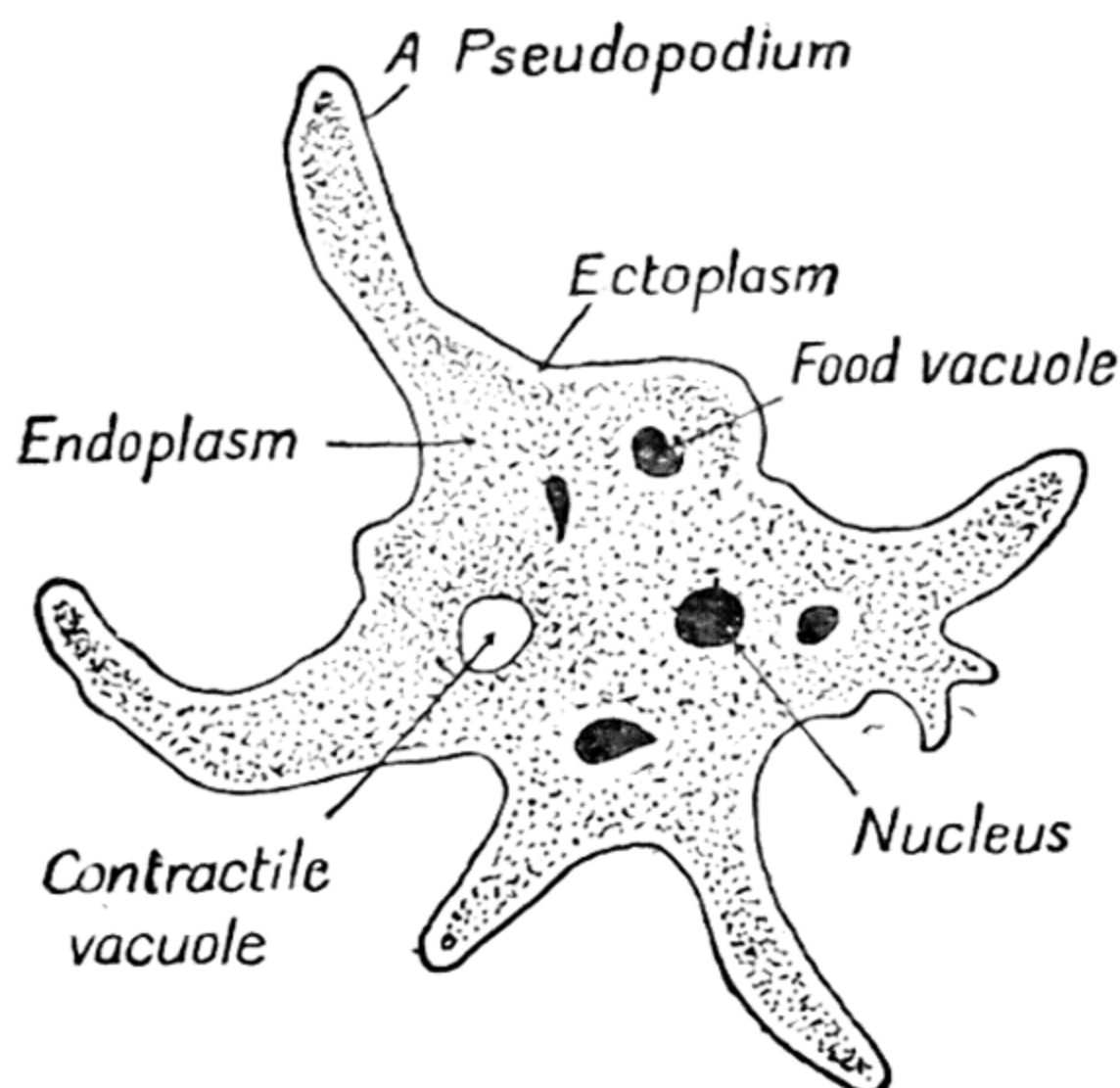


Fig. 118. — Amœba

moves, so its shape changes. Amœba has no definite fixed shape, and no front, back, or sides.

Like all other animals, an amœba must secure food in order to go on living. It feeds on minute particles of

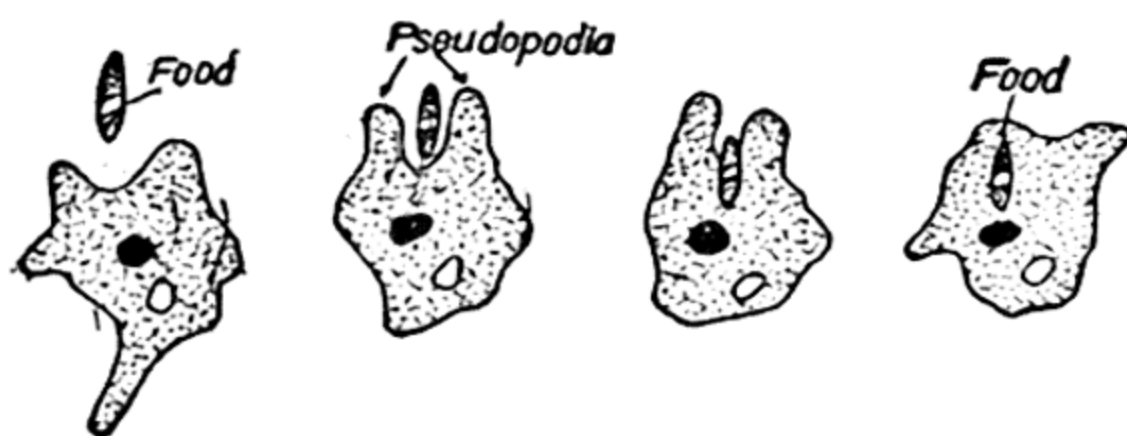


Fig. 119. — Amœba ingesting a food particle

plant or animal matter, and also on tiny microscopic plants known as Diatoms, even smaller than amœba itself. It secures its food by putting out two pseudopodia that gradually close round their capture, finally enclosing it, together with a tiny drop of water, in a

little clear space called a **food vacuole**. Inside this vacuole, juices formed by the amœba gradually dissolve out, or **digest**, the food present in the solid particle. Any indigestible residue is disposed of very simply by the protoplasm flowing away and leaving it behind.

At some point or other in the endoplasm there will be found a tiny clear space, which, if watched for a time, will be seen to grow larger until eventually it suddenly contracts and disappears, only to form again and repeat the process. This is a **contractile vacuole**,



Fig. 120. — Stages in the reproduction of amœba by fission

the function of which is **excretion**, the getting rid of excess water and the substances dissolved in it no longer required by the organism. The sudden contraction of the vacuole forces this liquid out of the protoplasm.

When an amœba reaches a certain size, it starts to reproduce. First of all the nucleus elongates, a constriction forms round the middle, and eventually the nucleus becomes divided into two smaller nuclei. Meanwhile a similar constriction begins to divide the remainder of the protoplasm into two more or less equal portions that separate, each containing one of the two nuclei. This method of reproduction is called **fission**. The adult amœba regains its youth by dividing to form two smaller ones, which, in turn, grow up and repeat the process when they are big enough. An amœba, therefore, never dies a natural death of old age. An amœba cannot live except in the presence of

moisture, and if its pool or damp earth dries up, it will die. Sometimes, however, it manages to tide over adverse conditions by forming round itself a protective outer covering or **cyst**, inside which it lies dormant. Should conditions become more favourable the cyst wall bursts open and liberates the amœba.

## The Nature of Protoplasm.

The tiny pieces of protoplasm that we call amœba show all the characteristics that we associate with life and with living things. All living things are capable of movement, of taking in food and of getting rid of unwanted substances, of responding to changes in their surroundings, and of increasing in numbers. All these characteristics are exhibited by such a simple mass of protoplasm as amœba, and while it exhibits them, and because it does so, it is said to be **alive**.

We should naturally like to know a lot about this remarkable substance, what it is made of, how it works, and so on. Unfortunately, our knowledge is still extremely limited, and one of the greatest difficulties in our way is the fact that as soon as we try to find out what it contains, to **analyse** it by treating it with chemicals, we immediately kill it. Thus anything we find out in this way is only something about dead protoplasm, which no longer has that wonderful property of "living".

Protoplasm is a colourless, almost transparent, and somewhat jelly-like substance, resembling in some respects the white of an egg before it has been cooked. But protoplasm is certainly a very complicated mixture of substances, some of which are more solid than the others. These more solid particles can be seen under a microscope as tiny granules. Protoplasm also contains a very large proportion of water, sometimes nearly 90 per cent. The protoplasm of a given plant

or animal differs slightly from that of any other kind of plant or animal.

### The Function of the Nucleus.

As the nucleus of amœba divides into two before fission takes place, it seems fairly clear that the nucleus is a very important part of the protoplasm. By means of very fine glass threads, it is possible to divide an amœba into two artificially. It has been found that the half containing the original nucleus continues to live and develop as though nothing had happened, but that the portion without a nucleus soon dies, apparently of starvation. It would seem that the nucleus acts in some way as a controlling centre for the rest of the protoplasm, and that it is especially associated with reproduction and with the absorption of food.

### Cells.

When a very thin slice or section of a plant is examined under the microscope, it is found to consist of an exceedingly large number of very small compartments, or **cells**, so called because in some of the specimens first examined they resembled in shape the cells of a honeycomb. There are, however, many different kinds of cell, each with its own shape, which is due to the fact that it has a rigid **cell wall**. The really important part of a plant cell is not its cell wall, which consists usually of a non-living substance called **cellulose**, but the contents of the cell. This consists of protoplasm with, nearly always, a nucleus, and usually a watery liquid called **cell sap**. Nevertheless, we often find in plants cells with specially thick walls and sometimes no living contents at all. The principal function of such cells is to give mechanical strength.

The bodies of animals also are composed of cells of various kinds, each consisting of a portion of proto-

plasm, together with its nucleus. Animal cells do not have a rigid cell wall. Various types of plant and animal cell are shown in fig. 121.

Very few cells are large enough to be seen with the naked eye, and a plant such as the snapdragon, or an animal such as man, is composed of countless millions of such tiny units. We have seen that an individual amœba consists of a single piece of protoplasm with a single nucleus. It consists, therefore, of a single cell. Organisms like amœba that are composed of only one

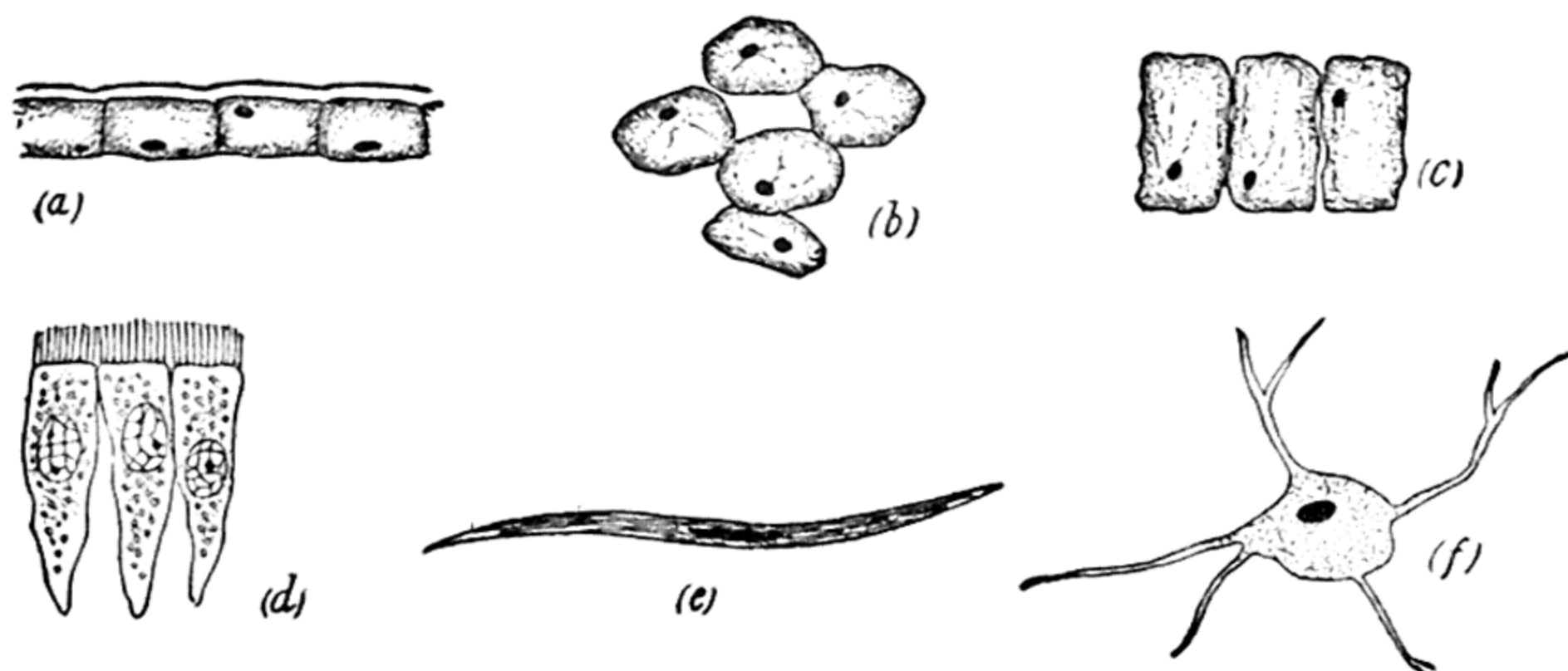


Fig. 121. — Types of Plant and Animal Cells

(a) Epidermal cells of leaf; (b) Parenchyma cells of leaf; (c) Palisade cells of leaf; (d) Ciliated cells from lining of wind-pipe; (e) Muscle cell; (f) Nerve cell.

cell are said to be **unicellular**. Those consisting of a number of cells are **multicellular**. In multicellular organisms we usually find cells of each particular kind arranged in groups or masses. Such a group of similar cells is called a **tissue**. In amœba every cell is alike, for each forms a complete organism, and each cell is able to undertake all the various kinds of activity of which the organism is capable — movement, absorption of food, reproduction, and so on. But in multicellular organisms, as a rule, cells specialize in one kind of activity; some cells will be concerned mainly with

the absorption of food, others mainly with reproduction, others mainly with movement, and so on. The differences between the various kinds of cells are due to the fact that each kind grows and develops in such a way as to make it more efficient at its own particular work. These differences, both in shape and in work, are more marked in animal than in plant cells.

## Spirogyra.

Spirogyra is a very common fresh-water weed, found floating on the surface of still water. It consists of innumerable fine green threads, and if one of these

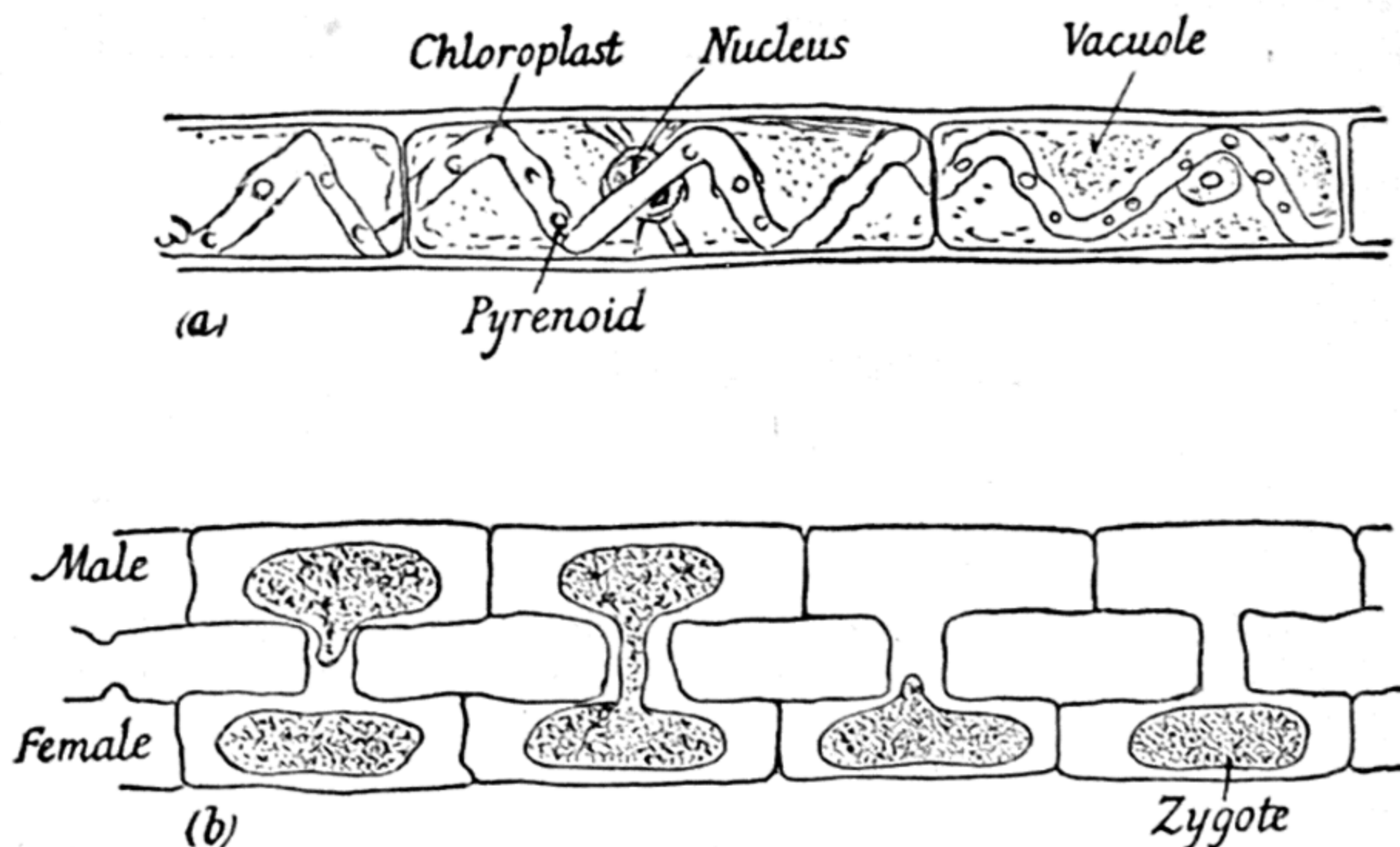
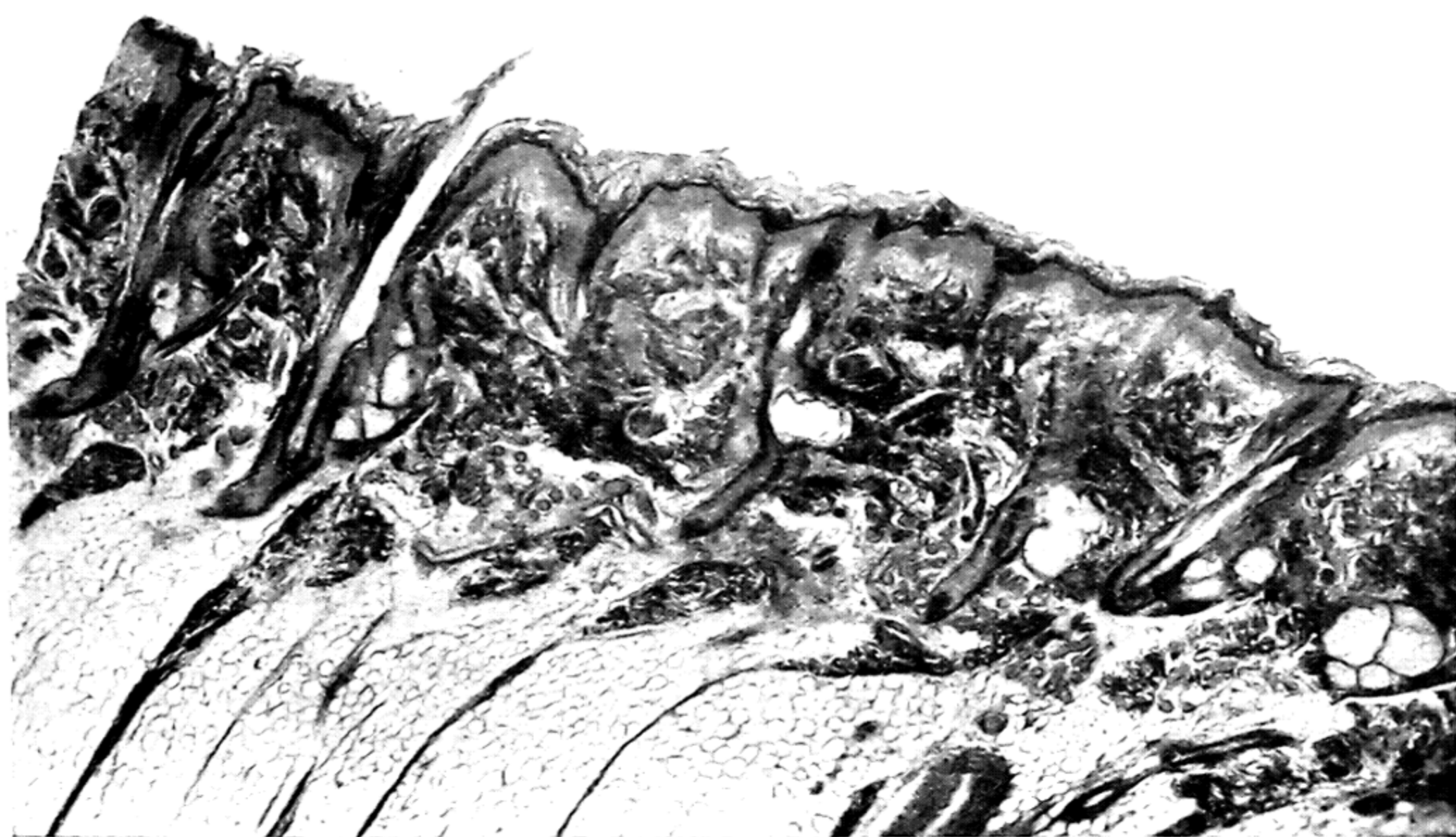


Fig. 122

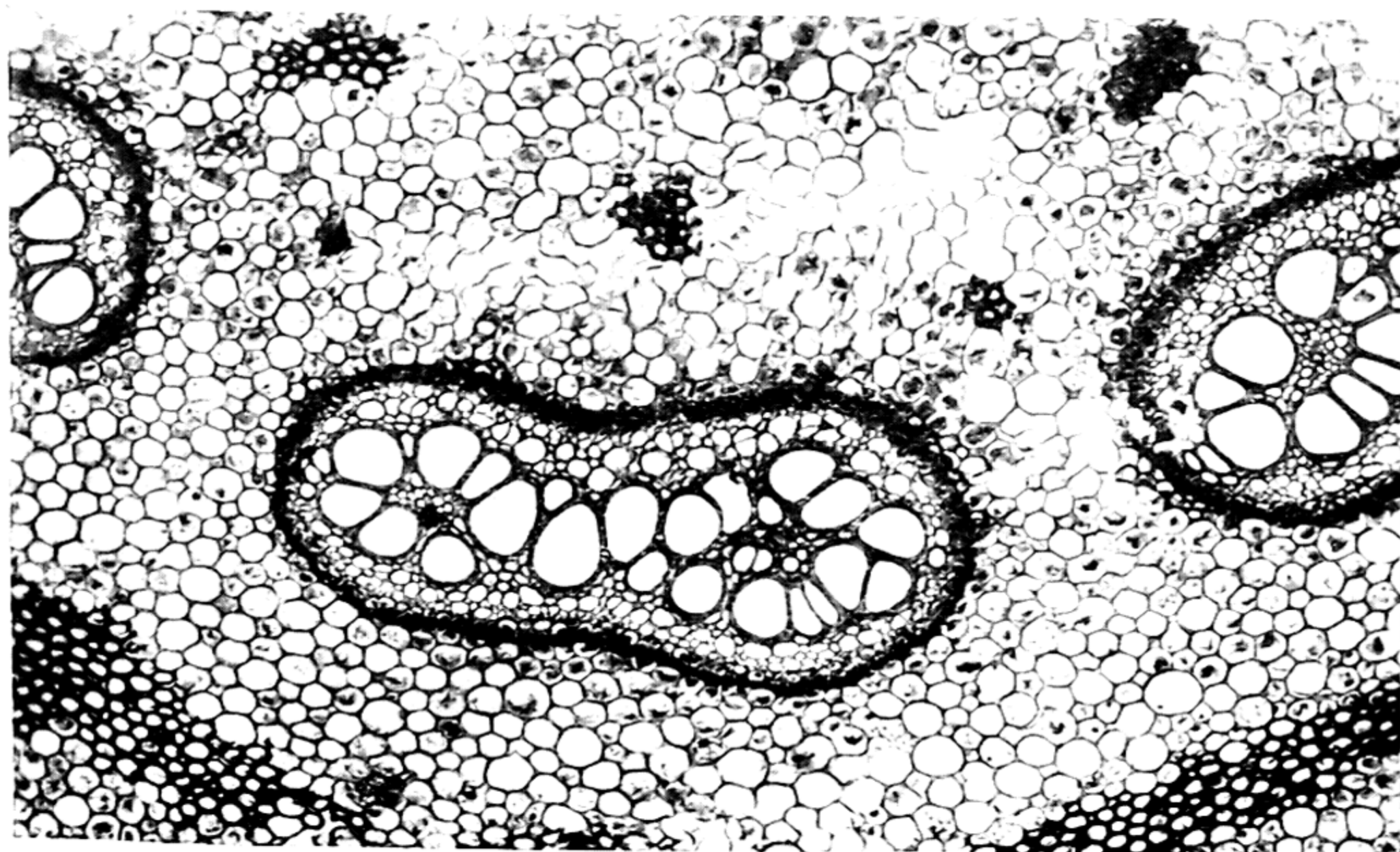
(a) Filament of spirogyra.

(b) Stages in the conjugation of spirogyra.

is examined under the microscope, it will be found to consist of a single row of cylindrical cells, all exactly alike. The slimy feel of the plant is due to a gelatinous layer on the outside of the cell walls. Along the inside walls of each cell is a lining of protoplasm, to which a nucleus near the centre of the cell is attached by threads of protoplasm. A striking feature of each cell is the



Vertical section of human skin, showing sweat glands  
and hair insertion ( $\times 22$ )



(Flatters and Garnet)

Part of a cross-section of the stem of a fern (*Pteridium  
aquilinum*) ( $\times 50$ )

PHOTOMICROGRAPHS SHOWING THE CELLULAR STRUCTURE  
OF PLANT AND ANIMAL TISSUES



**chloroplast**, a special part of the protoplasm which contains chlorophyll. The chloroplast (in some forms each cell contains more than one) is coiled up in the cell like a corkscrew, and the remainder of the cell is a large vacuole containing cell-sap.

Filaments of spirogyra increase in length by the formation of new cells. Fully grown cells divide into two, in a manner rather similar to amœba. First the nucleus divides, and then the rest of the protoplasm, but instead of the halves separating they remain in contact, separated by a new cell wall. The two small cells thus formed from one large one grow in size and eventually themselves divide. If a thread of spirogyra is broken in two each half will go on growing independently, and this forms, therefore, a method of vegetative reproduction.

Towards the end of the growing season spirogyra reproduces in a different way. Two filaments lie side by side and the cell walls bulge out and meet to form a short tube. The contents of each cell become almost spherical, and one of the spherical masses passes along the tube and fuses with the contents of the other cell, which then forms a thick wall and remains dormant for some time. The whole process is called **conjugation**, and the resting cell so formed is termed a **zygote**, a term used to denote the result of fusion of any two reproductive cells throughout the plant and animal kingdoms. The zygote escapes from the filament in which it was formed and eventually germinates to form a new filament. This form of reproduction is sexual, although, as the cells that unite appear exactly similar, we cannot call one male and the other female. We may perhaps consider that the one which moves down the tube is the male.

## Yeast.

Yeast is usually bought in the form of a solid cake. When a small portion of this is mixed with water it forms a milky liquid which, when examined under the microscope, is seen to contain an enormous number of small, somewhat egg-shaped cells, some single, some joined together in chain-like clusters. Each cell is about  $\frac{1}{100}$  mm. in diameter, is bounded by a cellulose wall,

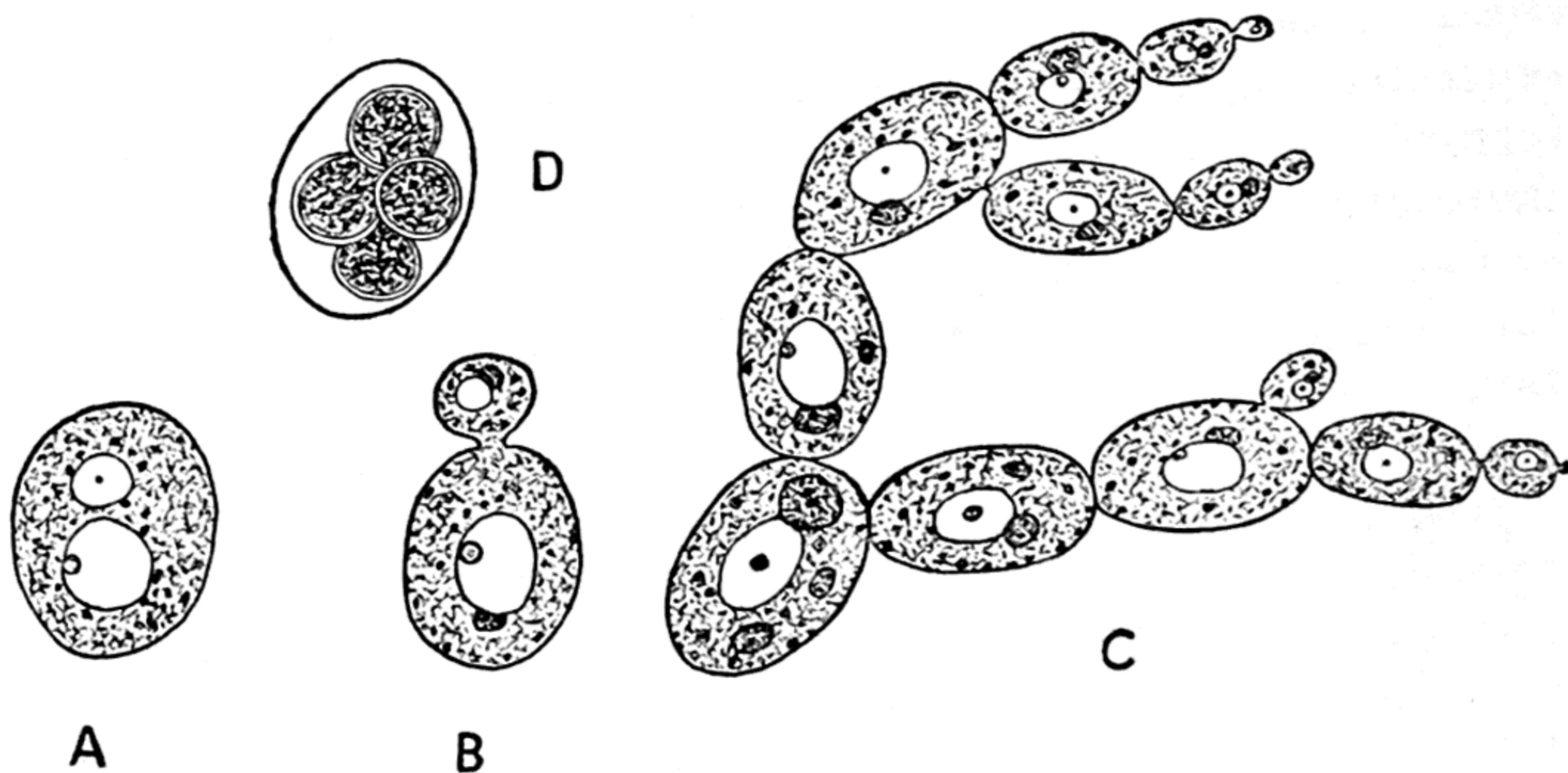


Fig. 123. — *Saccharomyces cerevisiae*, the yeast plant (highly magnified) A, Yeast cell. B, Yeast cell budding. C, A colony of living cells of brewers' yeast. D, Cell which has formed four thick-walled spores.

and contains a vacuole and a nucleus, although the latter can be seen only after the cell has been stained.

Yeast grows rapidly in sugar solutions provided the temperature is between 5° C. and 30° C. Very small amounts of certain other substances are also required for proper growth. Yeast cells reproduce by a process called **budding**. One or more bulges appear in the cell wall and grow larger, remaining joined to the parent cell by a narrow neck, across which is formed a cellulose wall. The daughter cells produced in this way will often themselves start to form new cells by budding

before they are detached from their own parent cell, and this gives rise to the chain-like clusters referred to above. When food supplies are running short, yeast reproduces in a different way. The contents of a cell divide up to form four rounded **spores**, each with a separate wall and capable of withstanding adverse conditions for a considerable time. Each spore, when it germinates, produces an ordinary yeast cell, which continues to reproduce by budding as long as food supplies are plentiful.

A sugar solution to which a little yeast has been added soon begins to "work" if kept in a warm place, and bubbles of gas come off. As a result of the activity of the yeast the sugar is converted into alcohol and a gas called carbon dioxide (see p. 260). This process is called **fermentation**.

**EXPERIMENT 56. — The fermentation of a sugar solution by yeast.** Take 200 c.c. of water in a flat-bottomed flask fitted with a lead-out tube as shown in fig. 165, and add 10 gm. yeast. Put the flask near a radiator, or in some other warm place, with the end of the lead-out tube under the surface of some lime-water in a bottle. Notice after a day or two the formation of bubbles of gas in the flask. Some of these, escaping from the end of the lead-out tube, have turned the lime-water milky, showing that the gas is carbon dioxide (see p. 262). When no further action seems to be taking place, filter off the yeast from the liquid in the flask, and distil over (see Exp. 39, p. 149) about 50 c.c. of the filtrate. This liquid will consist of most of the alcohol formed, together with water. To show the presence of the alcohol proceed as follows. Add a crystal of potassium bichromate and a few c.c. of dilute sulphuric acid. Warm over a bunsen burner. The solution turns green in colour and a vapour with a characteristic smell is given off. Verify that a dilute solution of alcohol gives this test by repeating it with water to which about  $\frac{1}{10}$  of its volume of methylated spirits has been added.

Although yeast contains no green colouring matter (chlorophyll) it is nevertheless a plant. It has a cell wall made of cellulose, a substance not found in animals,

and in other ways as well it resembles other organisms which do contain chlorophyll. Because it has no chlorophyll it is unable to manufacture its own food, and that is why it requires a sugar solution in which to grow.

### Uses of Yeast.

Since yeast is able to convert sugar into alcohol and carbon dioxide, it is very useful to man, and it has in fact been used from very early times. It is employed in the manufacture of industrial alcohol, in the brewing of beer, and in the making of bread. Industrial alcohol is usually prepared in Europe from potato starch, which is first converted into sugar. Yeast is then added, and when the fermentation is over the alcohol formed is distilled off and separated from the water that comes over with it.

The starting-point for the manufacture of beer is barley. This contains starch and, after the barley has been kept for a time in a warm moist place, it begins to germinate, during which process the starch is converted into sugar. When all the starch has been converted, yeast is added to water containing the germinating barley, or "malt", and the sugar is converted by the action of the yeast into alcohol and carbon dioxide. Beer usually contains from 3 per cent to 5 per cent of alcohol, together with sugar, colouring matter, a little dissolved carbon dioxide, and other substances to which it owes its flavour.

In the making of bread some of the starch in the flour becomes changed into sugar. When yeast (leaven) has been added, it ferments this sugar, and the carbon dioxide gas formed during the fermentation makes the bread porous or "light", and causes it to "rise".

## Moulds.

Bread, leather, and many other substances turn mouldy if exposed to air in a damp place, owing to the growth on them of a class of plant called **Moulds**. One of the commonest of these moulds is called **Mucor**. *Mucor* forms white patches, which, under a lens, are seen to consist of fine white branching threads. Each of these threads, or **hyphæ**, consists of a tube lined on the inside with protoplasm containing a number of nuclei not separated off into individual cells by cross walls. The tangled masses of hyphæ absorb food from the surface on which they grow, but they are unable to penetrate far below the surface, as they cannot grow in the absence of air.

When the mould has been growing for a few days, it sends up vertical hyphæ (fig. 124, *a*), the ends of which swell out into an almost spherical head separated from the rest of the mould by a partition, which bulges into the head. Most of the protoplasm of the vertical hypha passes into the head and there divides up into a very large number of spores.\* As the spore cases ripen they change in colour to brown or black, and the slightest touch is sufficient to cause them to burst open and discharge the very small light spores, which are able to remain dormant for some time. These spores are carried by the lightest of breezes and float about in the air, eventually settling on surfaces exposed to the air like particles of dust. It is difficult to realize how numerous and how all-pervading these spores are, not only of *Mucor* but of other moulds also. We have only to leave a piece of damp bread about for a day or two, indoors or out, and we may be sure that one or more of these spores will fall upon it and germinate to form hyphæ. It is easy to understand why so many spores are produced,

\* Spores differ from seeds in consisting of only one cell, while seeds consist of an enormous number and contain within them the young plant or embryo.

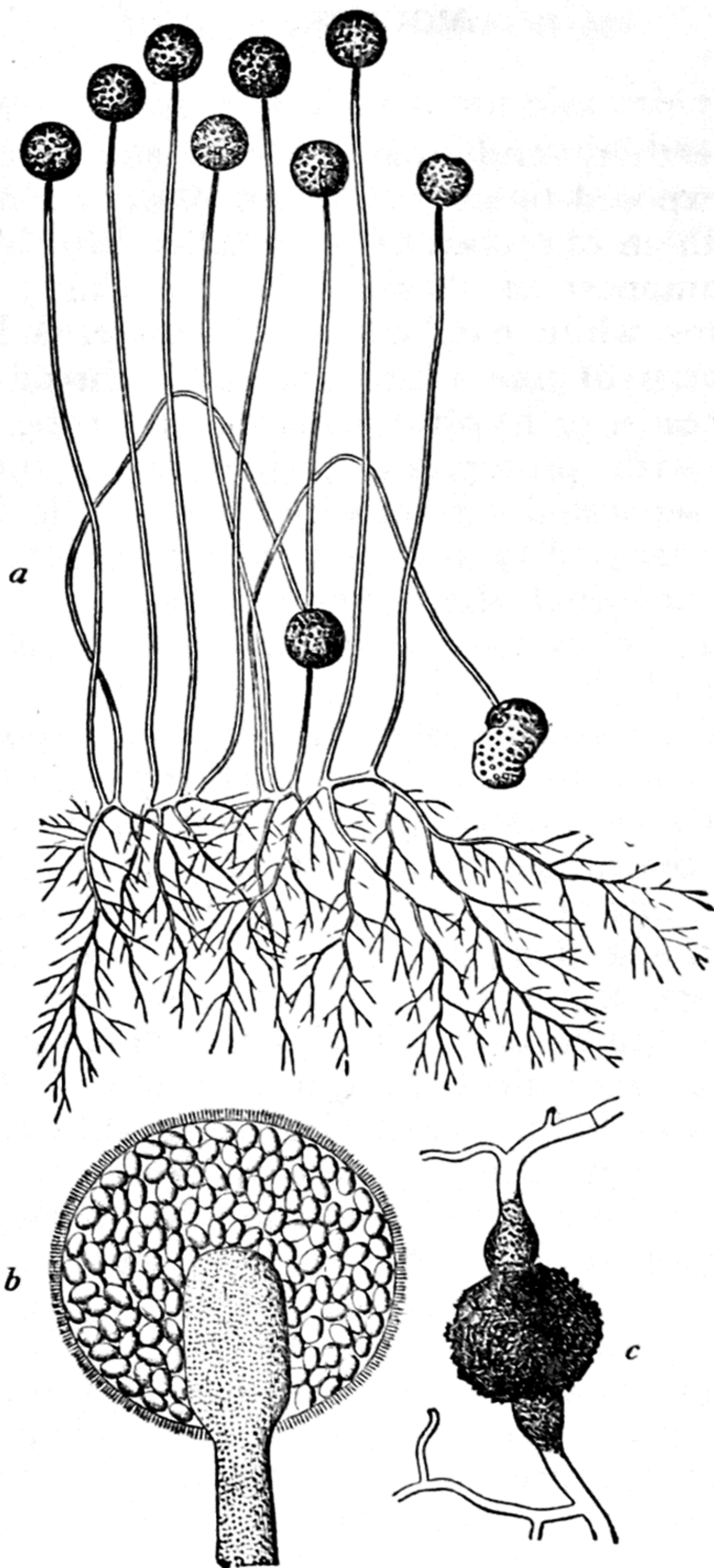


Fig. 124. — Common Mould Plant

(a) Branching network of hyphæ with erect hyphæ bearing spore cases.  
 (b) Head of vertical hypha showing spores. (c) Zygote.

since the vast majority of them must necessarily fall upon surfaces on which they will be unable to germinate, for, unlike seeds, they cannot grow on soil.

Under certain circumstances *Mucor* reproduces in another way. Two hyphæ growing close to each other send out branches that meet. The ends of the hyphæ become swollen, and most of the protoplasm of each makes its way to the swollen ends, which become cut off by cross walls. The walls separating the two ends then dissolve, and the two masses of protoplasm fuse together to form a single zygote, which surrounds itself with a dark, very thick, rough wall that enables it to survive very adverse conditions. When such a spore germinates it forms a short hypha which soon produces erect branches bearing spores. The method of reproduction described above is a sexual one, and is obviously very similar to that we have already considered in the case of *Spirogyra*. Conjugation in *Mucor* will only occur, as a rule, between hyphæ derived from two different spores.

## Fungi.

*Mucor*, like yeast, contains no chlorophyll. Both these plants belong to a large and important group of non-flowering plants called **Fungi** (sing. **Fungus**). Mushrooms and Toadstools also belong to the same group. None of these has any chlorophyll, although some of the toadstools are very brightly coloured. What we call a mushroom or a toadstool is not really the whole plant, but the **fructification**, the part that produces the spores. All the rest is below the surface in the form of colourless hyphæ, which absorb food from decaying vegetable matter in the soil or from living vegetable matter in such structures as a tree. The fructifications consist of enormous numbers of hyphæ growing together. The tiny black spores in the mush-

room are borne on the surfaces of the pinkish gills on the underside of the "umbrella".

Fungi, since they do not contain any chlorophyll, are unable, like green plants, to manufacture their own food, and so grow only on animal or vegetable matter from which they can get their food ready-made.

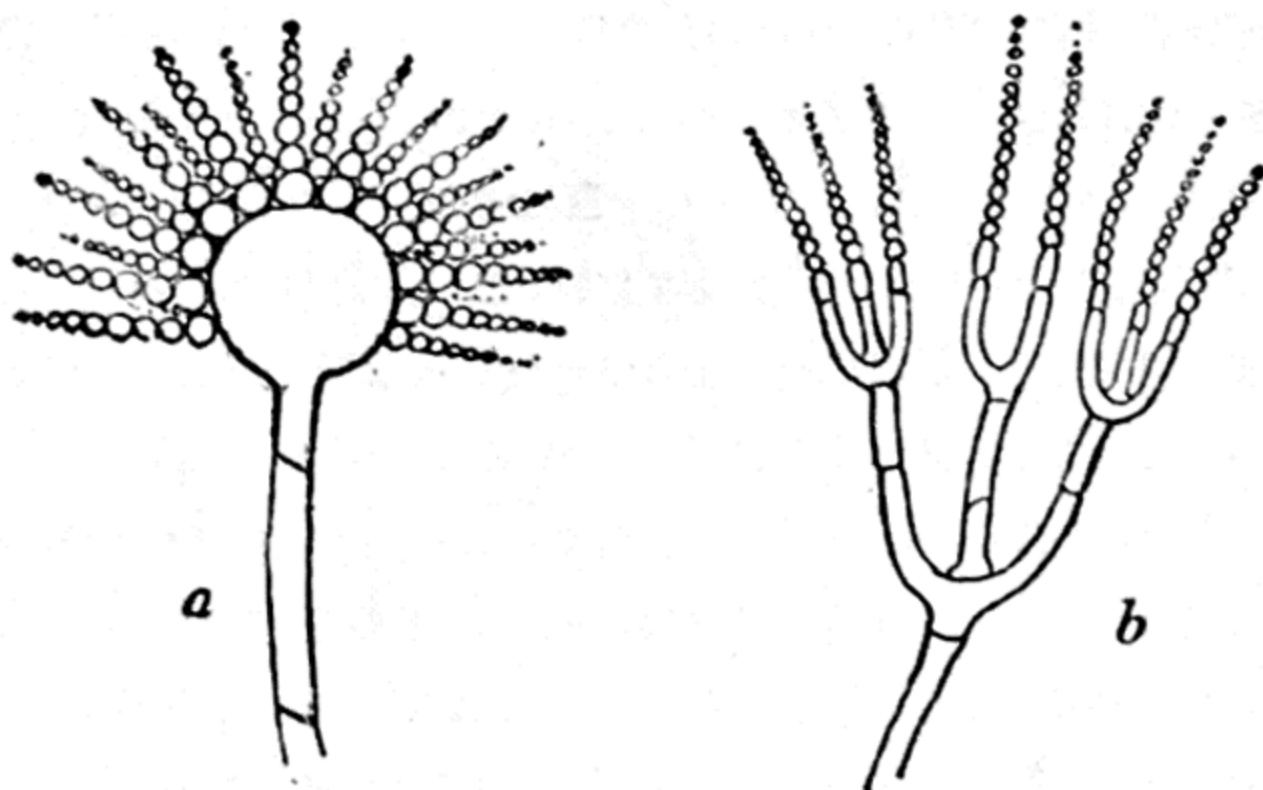


Fig. 125. — Two common Moulds  
(a) Penicillium. (b) Eurotium

**EXPERIMENT 57. — To grow and examine a mould.** Place a piece of damp bread in a small dish and cover it with a bell-jar. Leave in a warm place for a few days and then examine with a lens the various moulds that have formed. See if you can identify *Mucor*. Two other common moulds, blue-green in colour, are shown in fig. 125.

## QUESTIONS

1. What part does each of the following play in the life of an amoeba? (a) the nucleus, (b) pseudopodia, (c) the contractile vacuole?
2. Does an amoeba ever die? Give reasons for your answer.
3. How does amoeba reproduce?
4. What do you know about protoplasm?
5. What is a *cell*? What are the chief differences between plant cells and animal cells?
6. How does *Spirogyra* (a) grow, (b) reproduce?

7. What is yeast and what are its main uses?
8. Why does bread, jam, etc., go mouldy if left exposed to damp air? Would they go mouldy if they were kept dry?
9. Would you call amœba a plant or an animal? Give your reasons.
10. What is meant by *fermentation*, and how is it brought about?
11. What characteristics distinguish living matter from non-living matter? Illustrate your answer by reference to amœba.

## CHAPTER XII

### MECHANICS

#### **Force.**

Our everyday experience gives us some idea of **force**, a word employed in science with a very definite meaning. When we push or pull a body we apply a force to it, and, as a result, it will move, provided that the force we apply is sufficient to overcome any other forces that may be endeavouring to prevent the motion. Two of the commonest of these are **gravity** and **friction**. Gravity is the force that we have to overcome in order to lift a body up, while friction is a force that opposes any motion of one surface over another. Every body is attracted towards the centre of the earth with a force proportional to the quantity of matter or material in the body. It is this attraction which constitutes **weight**.

The pull of the earth on a body is less when the body is farther from the centre of the earth. The difference is negligible for a few feet, but 4000 miles from the earth the force of attraction is reduced to one quarter of its value at the earth's surface.

#### **Friction.**

If we press down firmly on the top of a table and then try to slide our hand along the table we have to exert a considerable force to maintain the movement. This is because the table exerts a backward force on our hand, opposing its motion. This opposing force is

friction — **sliding friction** in this case. No matter in what direction we try to slide our hand over the table the force of friction always opposes the motion. It is far easier to push a heavy object if the latter is mounted on wheels. This is because the wheels roll over the surface instead of slide over it, and sliding friction is now replaced by **rolling friction**, which is much less, although still always in such a direction as to oppose the motion. Note that friction only comes into play when we move or try to move an object. If it persisted after we had stopped pushing then the body would tend to move in the opposite direction, which it does not do.

The invention of the **wheel**, so essential to almost every form of transport, was one of the very greatest inventions ever made, for it enables us to move very much greater loads by reducing the frictional resistance. There is, however, this one additional requirement; we must have a hard surface for the wheel to roll on, for, if the surface is soft, the wheel sinks in and we have continually to exert force to lift the wheel out of the rut that it makes. For this reason sliding friction may sometimes be preferable, as, for example, over heavy snow.

Not only can a force cause a motionless body to move, it can bring a moving body to rest, and it can also change the direction of a moving body. Thus, when a cricket ball snicks the edge of the bat, the direction of the ball is changed by the force applied to it by the bat. We may sum up these effects of a force by saying that a force is **that which causes a body to change its state of rest or uniform motion in a straight line.**

It follows from this definition that, if we had a moving body on which there were no forces acting, the body would continue to move for ever in a straight line. This seems contrary to everyday experience, but in everyday experience we find it impossible to eliminate the

forces of gravity, of friction, and of air resistance. When we throw a body horizontally in the air it curves down to earth because of the attraction of gravity, and when we roll a ball along a level surface the forces of friction and air resistance soon bring it to rest. The smoother the surface on which we roll the ball the farther it will travel. Most of us at some time or other have thrown a stone along the surface of a frozen pond and been surprised how far the stone has travelled and how, after sliding over the ice for perhaps sixty or seventy yards, it has struck the edge of the pond travelling almost as fast as when it left our hand. This is because the friction between a smooth stone and ice is very small. Even here we cannot get rid of friction altogether; if we could, the stone would not slow down at all.

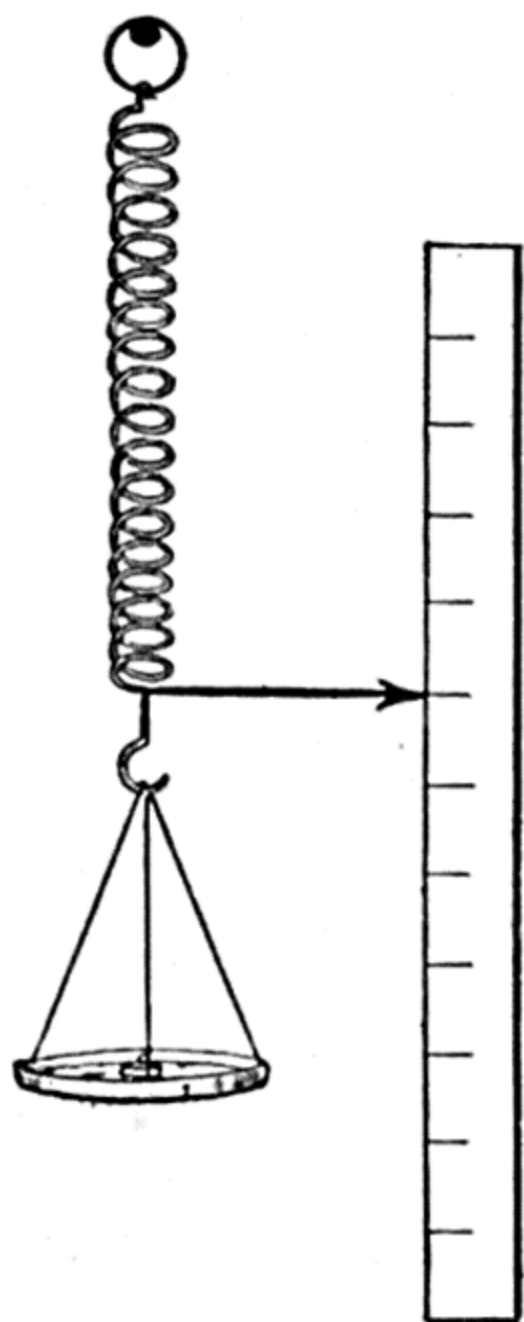


Fig. 126. — Extension of Helical Spring

We have seen that the weight of a body is a force acting vertically downwards, and we can therefore use weights as forces. Let us use them to find the effect of force on a helical spring.

**EXPERIMENT 58. — The stretching of a helical spring.** Suspend a helical spring vertically. Affix a light pointer to the lower end and attach also a scale pan. Fix a metre scale vertically so that the position of the pointer can be read. Note the original reading of the pointer. Place a 20-gm. weight in the scale pan and note down the new pointer reading. Add another 20-gm. weight and again read the pointer. Continue adding fresh weights, 20 gm. at a time, until the total weight in the pan is, say, 160 gm. Now take off the weights 20 gm. at a time

and obtain a fresh set of readings. It will be found that (1) the pointer reading is the same for a given weight in the pan whether the spring is being loaded or unloaded, and

(2) each increase in weight of 20 gm. causes the pointer to move through the same distance.

In the above experiment the spring was being stretched — it was in a state of tension. The results obtained verify the statement that **the extension is proportional to the tension (or stretching force)**. This statement is called Hooke's Law, after its discoverer, Robert Hooke (1635–1703), a very skilful and versatile experimenter and one of the foundation members of the Royal Society. The law is equally true for a wire, but in this case large forces are required in order to produce easily measurable extensions, so that special apparatus is necessary to show it in such cases.

In our experiment we did not load the spring above 160 gm. weight. If we had continued to load the spring we should eventually have reached such a load that when we subsequently unloaded the spring the latter would no longer have returned exactly to its original length, but would have a permanent set or extension. When we have a load which will just cause a permanent set, we have reached the **elastic limit**. If a wire is stretched beyond its elastic limit it soon reaches its **yield point** and breaks.

### Spring Balances.

If we had used a strip of plain paper instead of a metre rule in the above experiment, we could have marked on the paper the position of the pointer corresponding to each weight in the scale pan. The scale would have been evenly spaced, so that we could have subdivided it to read, say, every 5 gm. Our apparatus could then be used to weigh articles up to 160 gm. It is, in fact, an extension spring balance. Such instruments are often used in the laboratory for measuring weights and other forces when no very great accuracy is required. The usual form is shown in fig. 28 (p. 33).

When the spring is compressed we find that a similar law is obeyed, the change in length being proportional to the force acting. Ordinary kitchen scales are usually compression spring balances in which the change in length of the spring is caused to rotate a pointer in front of a graduated scale (fig. 129, p. 187).

### The Pulley.

Weight is a force that always acts downwards, but by a simple device we can use it to give us a force acting in any direction we like. This device is called a **pulley**

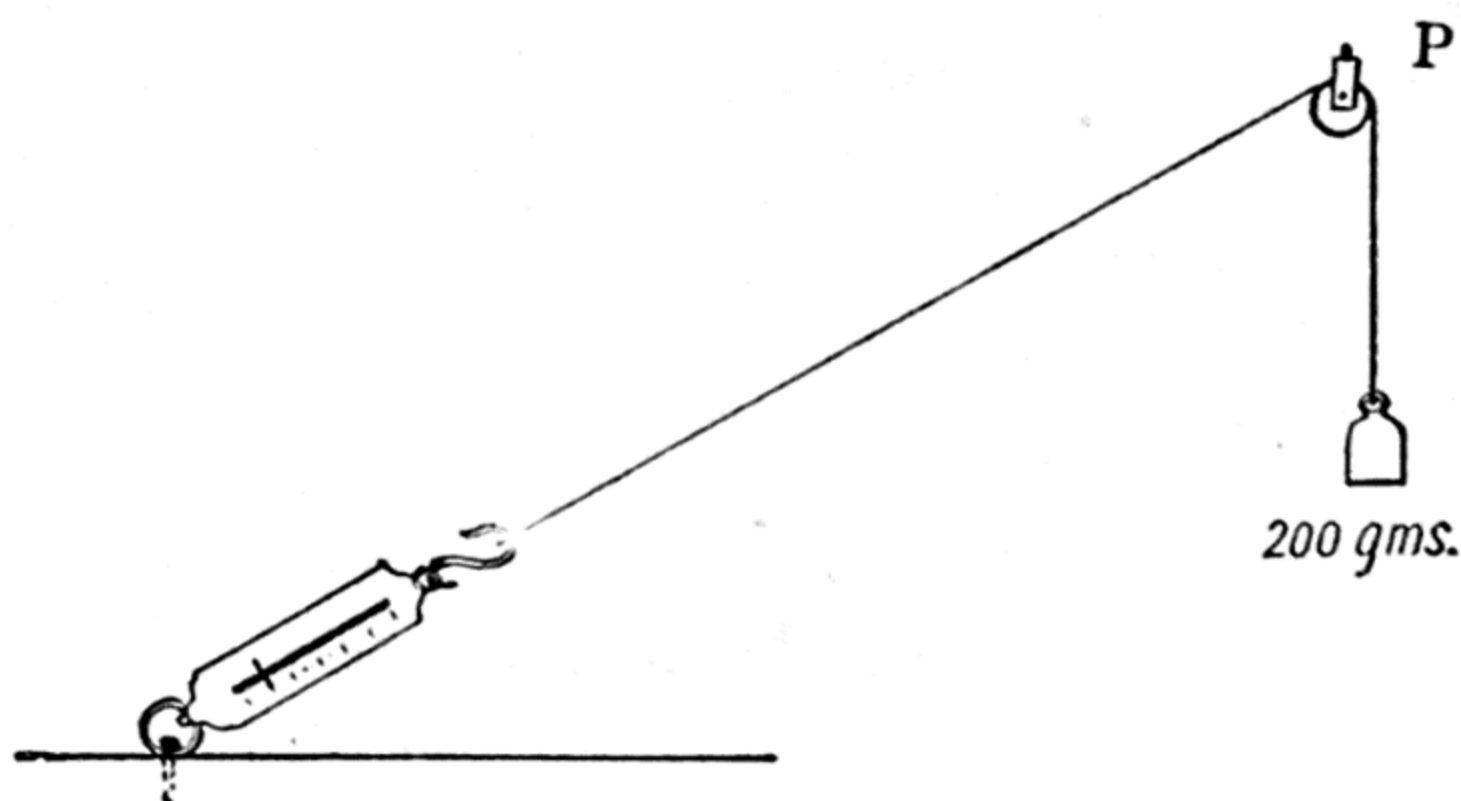


Fig. 127.— Changing the direction of force by means of a pulley

and consists of a grooved wheel which can rotate on an axle. If we attach a string to the hook of a spring balance (fig. 127), pass the string over a pulley *P* and hang a 200 gm. weight on the end of the string, we find that the balance records a pull of 200 gm. weight no matter what is the direction of the string joining it to the pulley, provided that there is no friction at the latter. In practice we cannot altogether eliminate friction, but with a good pulley it is very small. The weight puts the string into a state of tension which is transmitted to the other end of the string, the pulley allowing us to alter the direction of the force. This fact is often made use of

by builders, who fix a pulley at the top of a building and pass a long rope over it. Buckets of sand, cement, etc., can now be raised to the top of the building by a man at the bottom who pulls downwards on the other end of the rope. The same force is required as if the bucket had been pulled upwards from the top, but it is much more convenient to pull downwards than to pull upwards, and in this case also safer.

### Parallel Forces.

When we put a 100-gm. weight on a spring balance, and then add a second 100-gm. weight, the spring balance is pulled out the same distance as it is stretched by a single 200-gm. weight. That is to say, when two forces act on a body in the same direction, their combined effect is equal to the sum of the two forces and also acts in the same direction. This, of course, is obvious, and it is equally clear that when two forces act on a body in the same straight line but in opposite directions, their combined effect is equal to the difference of the two forces. Thus, a force of 10 lb. weight vertically upwards, together with a force of 15 lb. weight vertically downwards, is equivalent to a force of 5 lb. weight vertically downwards. This last force, which is equivalent to the combined effect of the other two, is called their **resultant**, of which the two original forces are the **components**.

The matter is not quite so simple when the forces are not all in the same straight line. We shall consider the case first when the directions of all the forces are parallel.

**EXPERIMENT 59. — To investigate the action of parallel forces.** Take a light wooden rod and suspend it from one or more spring balances (fig. 128, *a* and *b*). Note the readings of the spring balances, which give us the weight of the rod. Now suspend weights from various positions on the rod, adjusting them so that the rod remains level. The weights represent

*downward* forces, and the readings of the spring balances give us the *upward* forces exerted on the rod by the strings, which are in a state of tension. It will be found that the sum of the downward forces is equal to the sum of the upward forces. If we add another weight to the rod, the upward forces

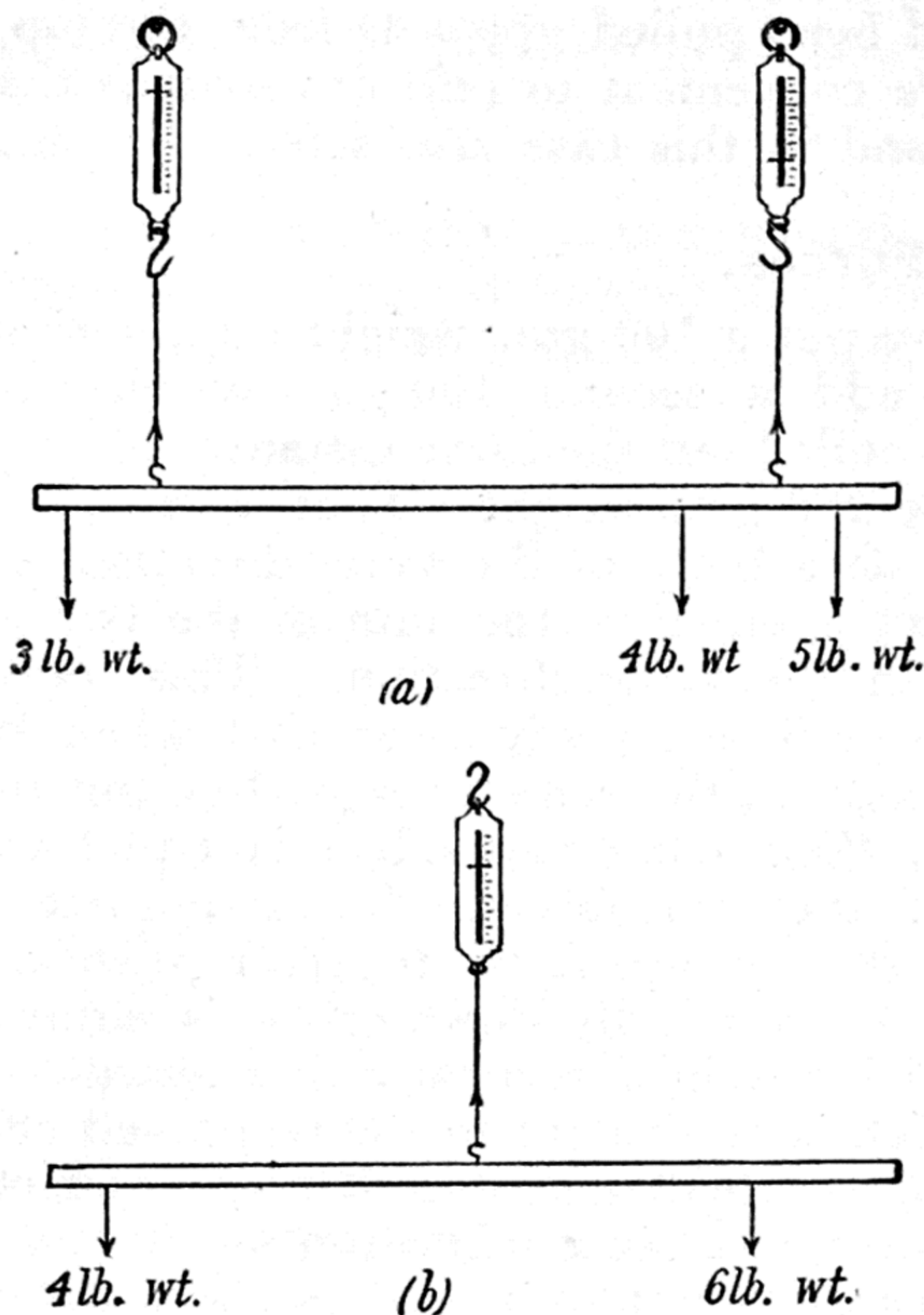


Fig. 128. — The action of parallel forces

no longer balance the downward ones, and so the rod moves downwards until the increased stretching of the springs causes sufficient increase of tension in the strings to balance the additional weight. The rod is then in equilibrium again, and remains at rest.

The above experiment may be repeated, using a compression balance instead of an extension balance (fig. 129).

Ordinary kitchen scales can be used by removing the pan and re-adjusting the pointer to zero. The pointer will indicate the sum of the downward forces. Since the rod is in equilibrium we should expect there to be an upward force on it equal to the sum of the downward forces. It is not obvious where this upward force is. The weighted rod is compressing the spring, which, however, resists compression, and so is able to exert an

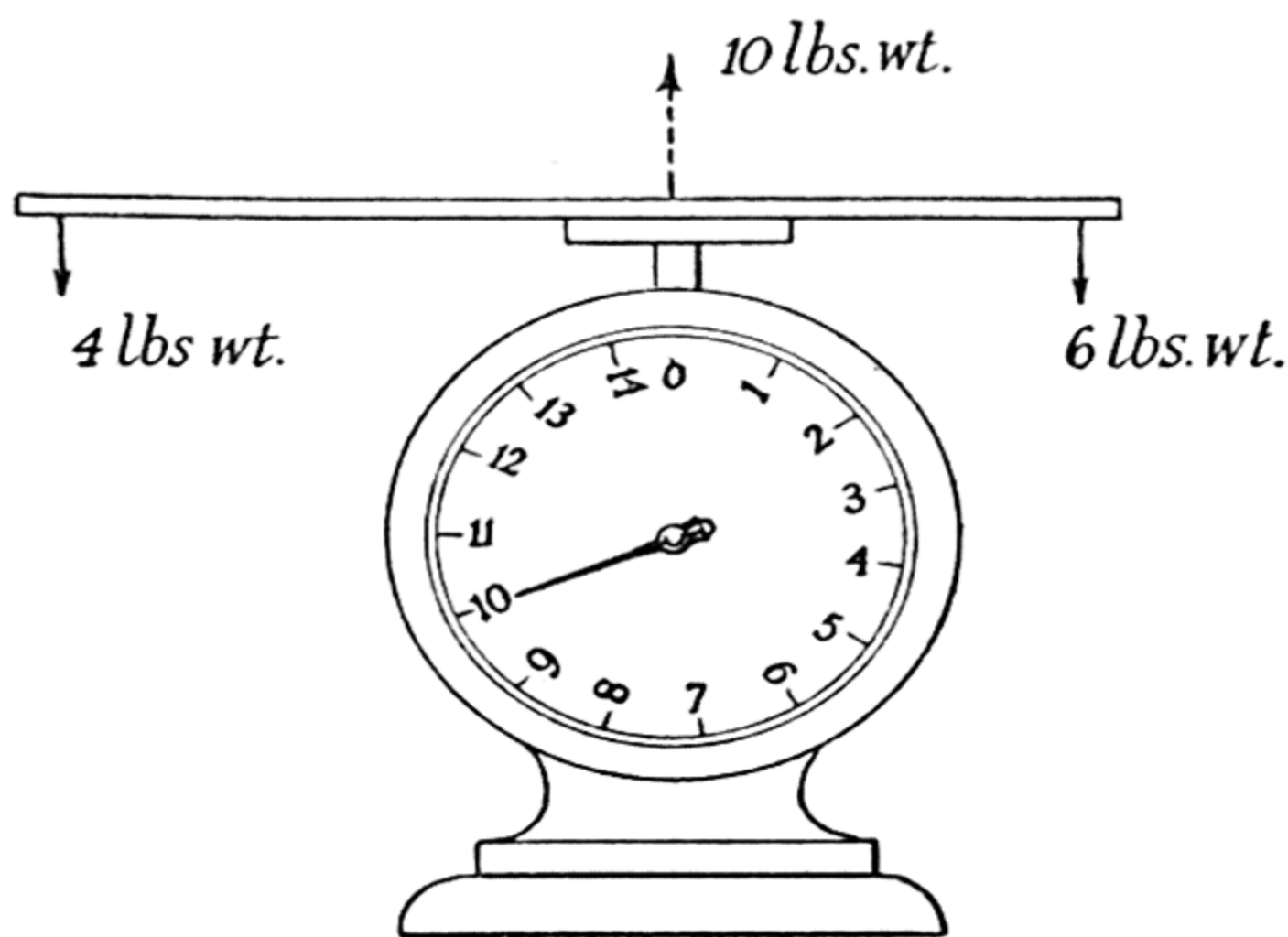


Fig. 129. — The action of parallel forces

upward force on the rod where the latter rests on top of the balance. Such a force is called a **reaction**. When a book rests on a table, its weight pulls it downwards, but it does not move because the table exerts an equal upward force, or reaction.

### The Turning Effect of Forces.

It is clear that if we attach a weight to the right-hand side of a rod pivoted on an axle passing through a hole at its centre (fig. 130) the weight will cause the rod to turn or rotate about the axle in a clockwise direction. A weight on the left-hand side would cause

the rod to rotate in an anti-clockwise direction. By putting a weight on each side and adjusting their distances from the axle so that the rod remains horizontal we can make these two opposing turning effects balance each other. The turning effect of a force does not depend only on the size of the force, because if we put equal weights on each arm they balance only when they are at equal distances from the centre of rotation or

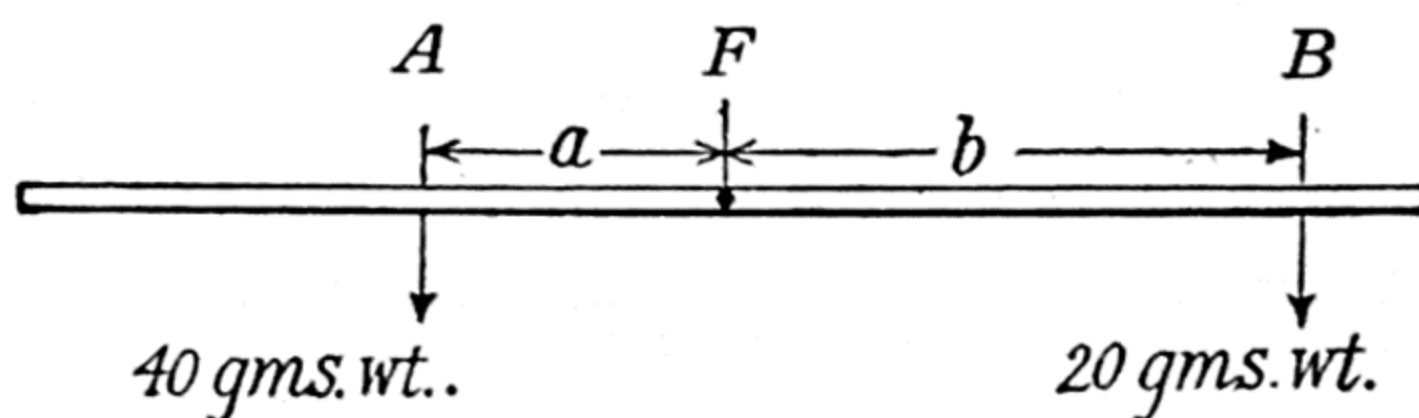


Fig. 130. — Balancing forces

fulcrum. When one is at a greater distance than the other from the fulcrum it exerts a greater turning effect.

**EXPERIMENT 60. — To study the turning effects of forces.** Take, say, a 40 gm. weight and suspend it from the left-hand side of a rod, pivoted at its mid-point, at a point A,  $a$  cm. from the pivot. Now suspend a weight of 20 gm. at B on the right-hand side so that the rod is in equilibrium. Let the distance of this weight along the arm be  $b$  cm. Repeat, using in turn on the right-hand side weights of 30 gm., 40 gm., etc., up to 80 gm. Tabulate your results thus:

Weight at A	Length $a$	Weight at B	Length $b$	(Weight A) $\times$ (Length $a$ )	(Weight B) $\times$ (Length $b$ )
40 gm.	25 cm.	20 gm.	50 cm.	1000 gm.-cm.	1000 gm.-cm.

It will be found that the product of the left-hand weight multiplied by its distance from the fulcrum is equal to the product of the right-hand weight multiplied by the distance of the right-hand weight from the fulcrum. A further point remains to be noticed. Suppose

that, instead of both the forces being vertical, and therefore at right angles to the rod, one of them had been oblique to the rod (fig. 131). A 4-lb. weight attached at B is sufficient to balance the weight at A, but if the force at B is applied obliquely, as shown in the figure, a larger force of more than 4 lb. weight is necessary, and the more obliquely the force acts the larger it must be for equilibrium. We find that the turning effect or **moment** of the force about the fulcrum is equal to the

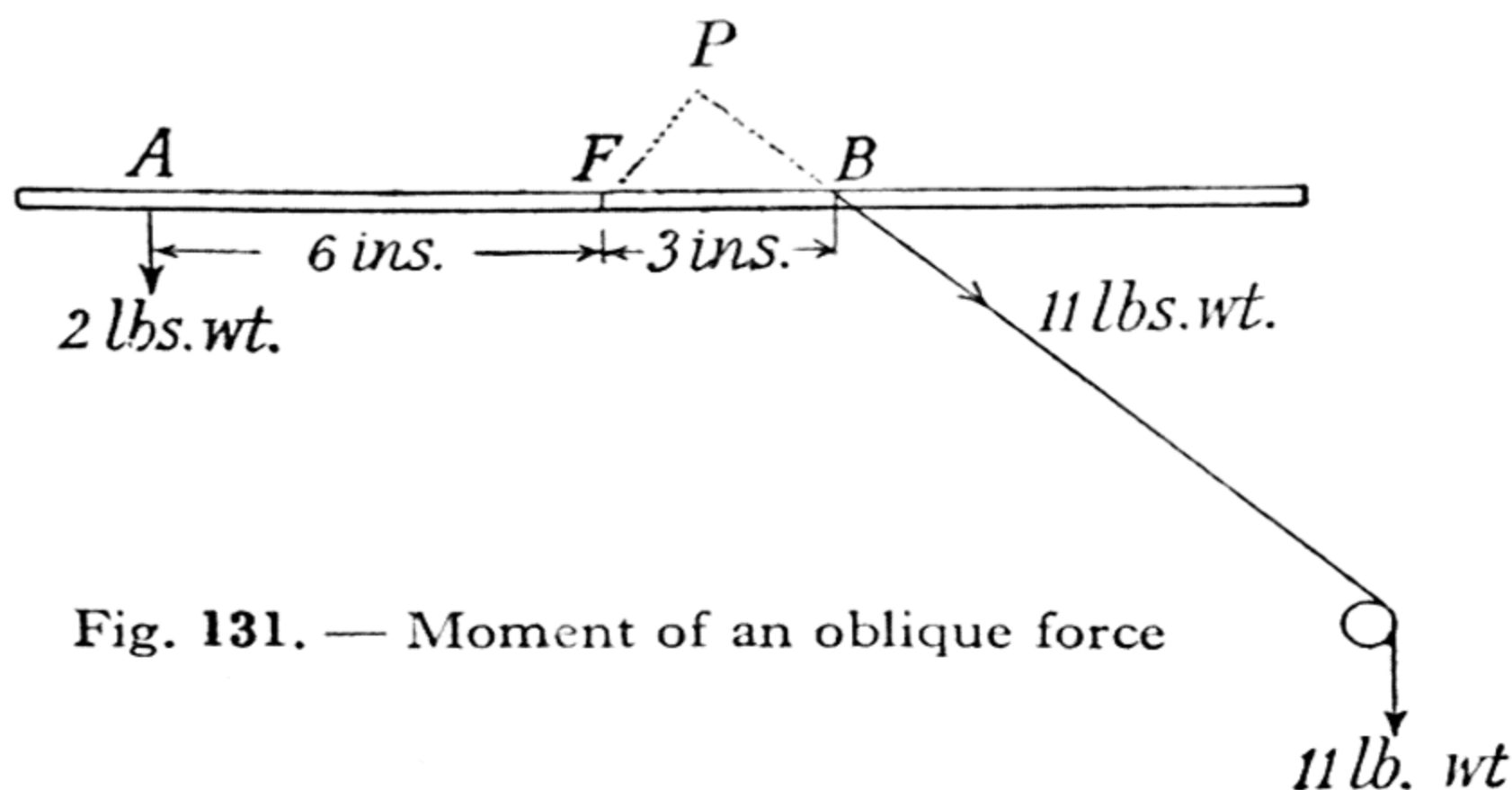


Fig. 131. — Moment of an oblique force

size of the force multiplied by the length *FP*, the perpendicular from the fulcrum on to the direction, or **line of action**, of the force. The more obliquely the force acts, the shorter *FP* becomes, and so the smaller becomes the turning effect or moment of the force.

We may measure, then, the **moment of a force about a point by the product of the force and the perpendicular distance of its line of action from the point.**

From the above experiment we see that two forces tending to turn a body will balance if the clockwise moment of the one force about the centre of rotation is equal to the anti-clockwise moment of the other force. We can extend this to the case of any number of such forces acting on a body — for equilibrium, the

sum of all the clockwise moments must equal the sum of all the anti-clockwise moments. This is called the **Principle of Moments**, or the **Law of the Lever**.

In fig. 132, the sum of the clockwise moments is

$$5 \times 3 + 3 \times 7 = 36 \text{ lb.-in.}$$

and that of the anti-clockwise moments is

$$2 \times 9 + 3 \times 6 = 36 \text{ lb.-in.}$$

so the rod will be in equilibrium. It should be noted that there is another force acting on the rod which we have not considered, namely, the upward reaction at the fulcrum. This is a force of

$$2 + 3 + 5 + 3 = 13 \text{ lb. weight (see Experiment 59).}$$

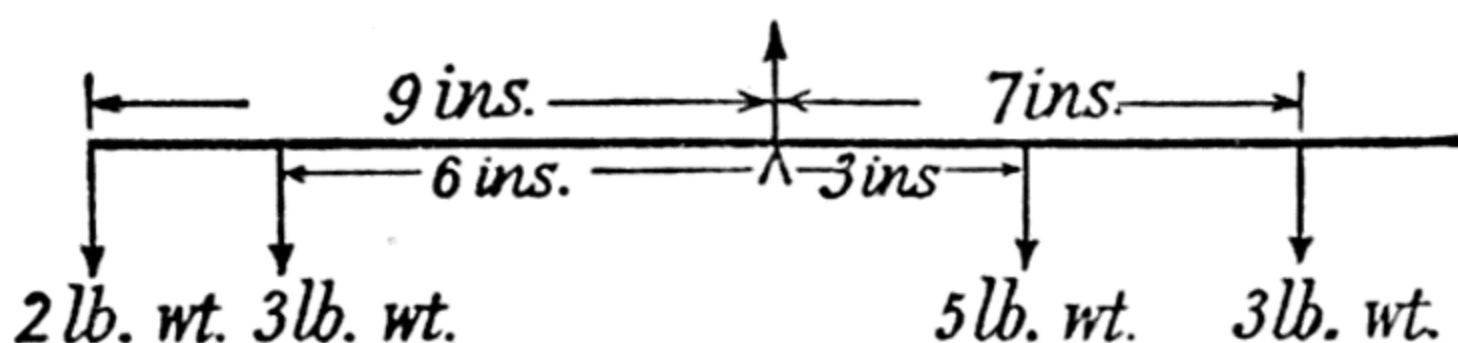


Fig. 132. — Law of the Lever

This force has no moment or turning effect about the fulcrum, for its line of action passes through the fulcrum, and so the perpendicular distance of its line of action from the fulcrum is zero. We can therefore neglect this force so far as rotation about the fulcrum is concerned.

## Levers.

The Principle of Moments finds innumerable applications in many types of lever. In all levers we apply a force called the **effort** (E) at one point on the lever to overcome a **load** (L) or **resistance** (R) at another point, a third point called the **fulcrum** (F) being fixed. Various examples of levers are shown in fig. 134. In

the common balance (fig. 134, *a*) the two arms are equal in length so that the scales are in equilibrium when the weights in each pan are equal. It is more usual for the arms of levers to be unequal in length. If the **effort** arm is longer than the **load** arm, we can use a comparatively small force to overcome a much larger one. In this way we obtain a **mechanical advantage**.

$$\text{Mechanical Advantage} = \frac{\text{Load moved}}{\text{Effort applied}}$$

Levers are sometimes divided into three orders, according to the position of the fulcrum (fig. 134). In the second order lever (fig. 134, *b, c*), the effort is always less

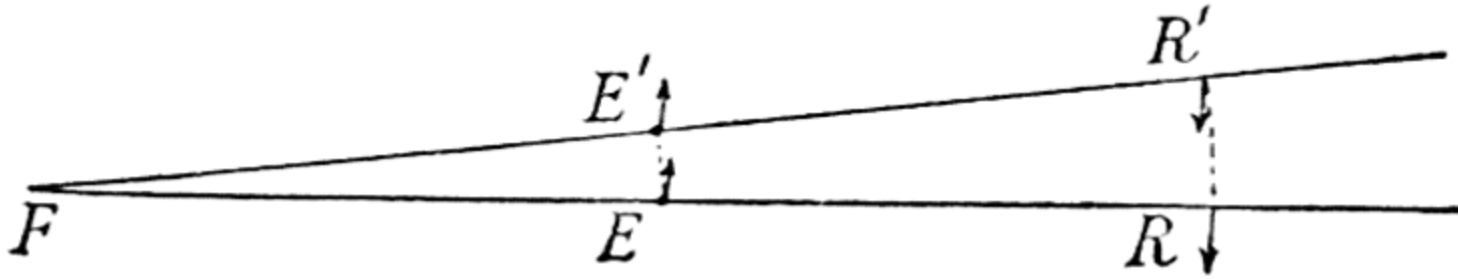


Fig. 133. — Principle of Work

than the load, so that the mechanical advantage is always greater than 1, but in the third order lever (fig. 134, *e*) the effort is always greater than the load, and here the mechanical advantage is less than 1. It might at first sight seem strange that we should ever trouble to use a lever that has a mechanical advantage of less than 1, but we do so for one or both of the following reasons: such a lever may enable us to apply a force under circumstances in which it would be impossible or very inconvenient to apply a force directly, and secondly it enables us to move the load a greater distance than the effort moves. From fig. 133 it will be seen that, while the effort moves the distance  $EE'$ , the load moves the greater distance  $RR'$ . The ratio

$$\frac{\text{distance moved through by effort}}{\text{distance moved through by load}}$$

is called the **Velocity Ratio**. From the geometry of fig. the velocity ratio  $\frac{EE'}{RR'}$  is equal, by similar triangles, to  $\frac{FE}{FR}$ , which, in turn, is equal to  $\frac{\text{Load}}{\text{Effort}}$ , by the Principle

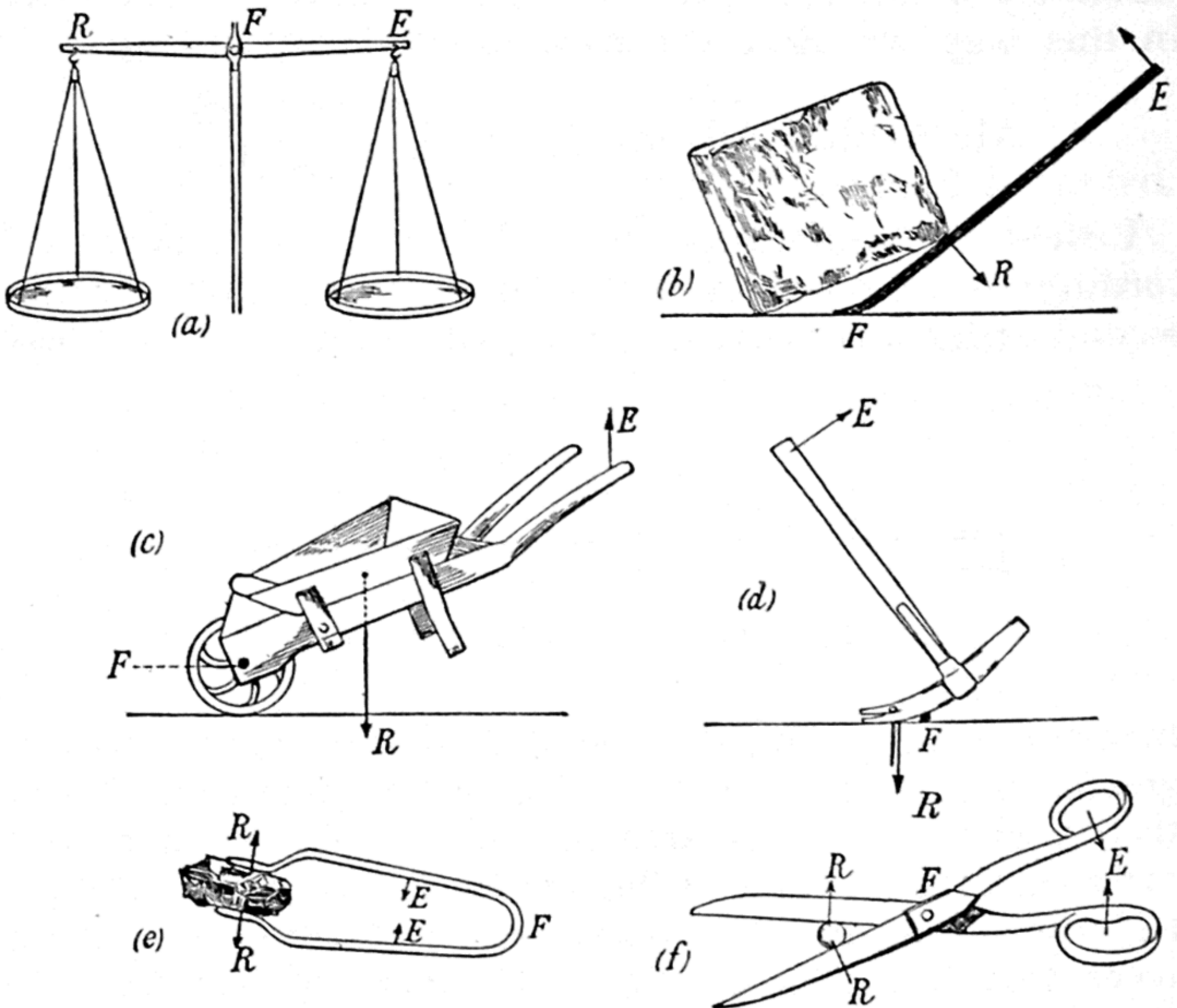


Fig. 134. — Types of Lever in everyday use

of Moments, so that the velocity ratio of a lever is equal to its mechanical advantage. We shall see later that this statement requires modification when we are dealing with practical cases from which we are unable to eliminate friction (see p. 199). When we use a lever with a large mechanical advantage, we have to move the effort a correspondingly greater distance than the load moves.

Levers in everyday use are not always straight, they

may be bent about the fulcrum (fig. 134, *d*), and sometimes they are **double**, consisting of two levers working in opposite directions but with a common fulcrum (fig. 134, *e* and *f*). The effort, or the load, or both, may be applied obliquely to the lever but we get the maximum turning moment from these forces when they act at right angles to the lever arms.

A very important example of lever action is the working of muscle in animal. The upper arm in man contains a bone called the **humerus** (fig. 135),

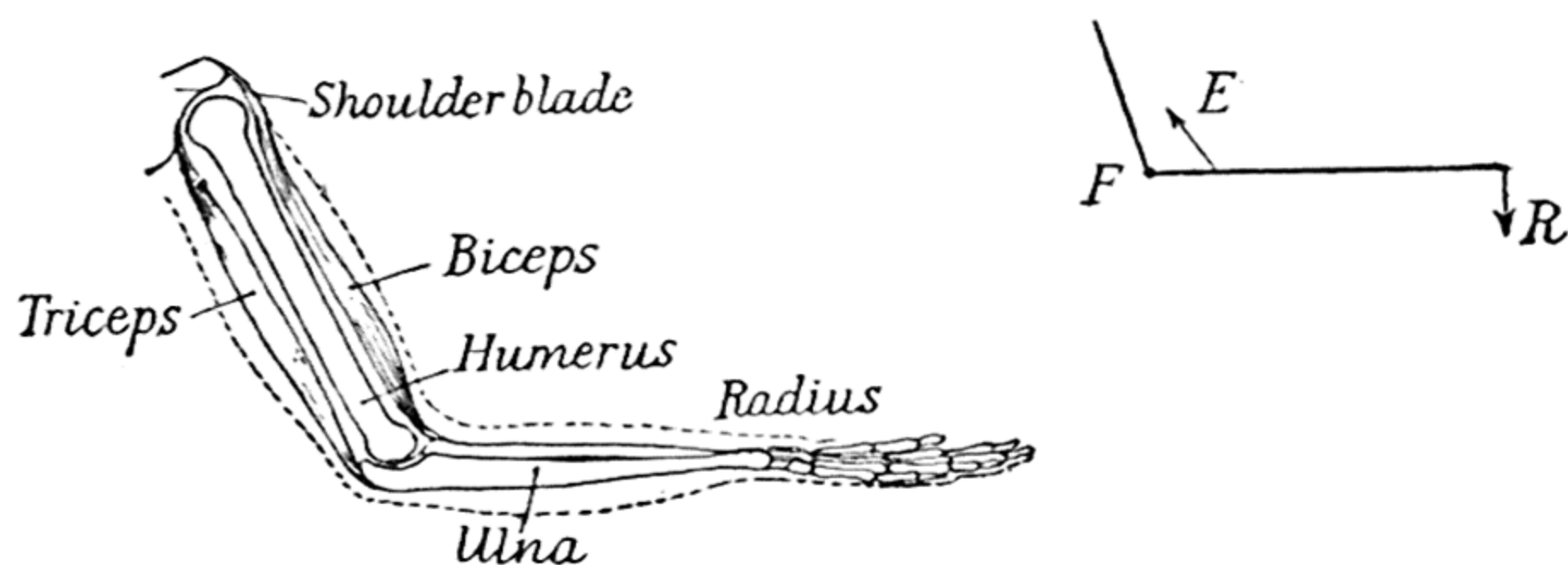


Fig. 135. — The human forearm as an example of a lever

which is jointed on to the **scapula**, or shoulder blade, at the top, and to the two bones of the lower arm, the **radius** and **ulna**, at the elbow. A large muscle called the biceps muscle is attached by tough **ligaments** or **tendons** to the shoulder-blade at one end and to the radius about  $1\frac{1}{2}$  in. from the elbow at the other (fig. 135). When a muscle contracts it gets shorter and thicker, and by the contraction of the biceps the resistance due to the weight of the lower arm and of anything held in the hand is overcome. This is an example of a third order lever, and the mechanical advantage is only about  $\frac{1}{10}$ , so that the force exerted by the muscle is ten times the load raised. To compensate for this, a small change in the length of the muscle produces a considerable movement of the hand, which can be

brought about very quickly. A muscle resembles a string in that, while it can transmit a pull or tension, it cannot transmit a push or **thrust**. Another muscle is therefore necessary to allow us to straighten the arm after it has been bent. This is the **triceps** muscle attached to the shoulder blade at the top and to the tip of the ulna at the bottom. The elbow joint acts as the fulcrum, as in the case of the biceps muscle.

### Pulleys.

There are several other devices besides the lever that will give us a mechanical advantage. We have already seen (p. 184) the use of a fixed pulley to change the direction of a force. By using one or more movable pulleys we can obtain a mechanical advantage. If we

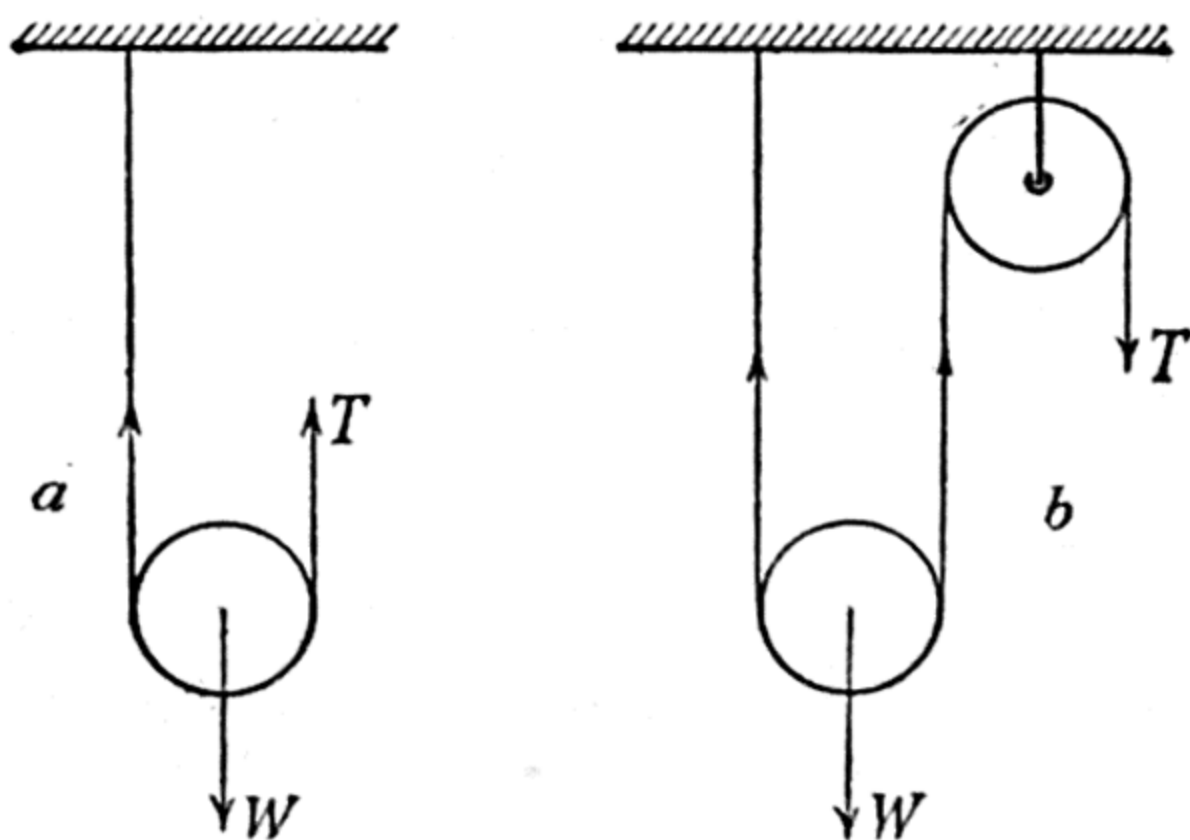


Fig. 136. — Pulley Systems

pass a string round a movable pulley, as in fig. 136 (a), and pull upwards on the free end of the string with a force  $T$  lb. weight, then, since the tension of a string does not change when it passes round a smooth pulley, there will be the same upward tension in the string on the other side of the pulley. The pulley, and the weight  $W$  attached, is therefore supported by *two* strings each having a tension  $T$ . When the pulley is in equilibrium

we shall have  $2T = W$ , or the force required to hold the weight in position is equal to only half the weight and the mechanical advantage of the arrangement is equal to 2. The other half of the weight is supported by the beam to which the fixed end of the string is attached. But once again what we gain in force we lose in distance, for when we raise the free end of the string 2 ft. the weight rises only 1 ft., the other foot being accounted for by the shortening of the string on the fixed side. The velocity ratio, therefore, is equal to 2, and, as in the case of a lever, we have the velocity ratio equal to the mechanical advantage. Here again we are assuming that there is no friction and we are also neglecting the weight of the pulley. In most cases it would be more convenient to use an additional fixed pulley to enable us to apply the force  $T$  downwards instead of upwards (fig. 136, *b*). Higher mechanical advantages can be obtained by using more pulleys.

In the system shown in fig. 137, we have three fixed pulleys mounted in one **block** and three movable pulleys mounted in the other and lower block. The same string passes round them all, so the tension is everywhere the same and equal to  $T$ . We see that the weight  $W$  and the lower block are supported by six upward forces each equal to  $T$ . For the equilibrium therefore  $T = \frac{W}{6}$ . The mechanical advantage of the

arrangement is therefore 6, but when the free end of the string is pulled down 6 ft. the weight is raised only 1 ft. In practice, the separate pulleys are the same size and are mounted side by side in the block on a common axle (fig. 138). The weight  $W$  lifted includes the weight of the lower pulley block, so that, if this was 2 lb. wt. and  $T$  was 5 lb. wt., for equilibrium  $W$  would be  $6 \times 5 - 2 = 28$  lb. weight.

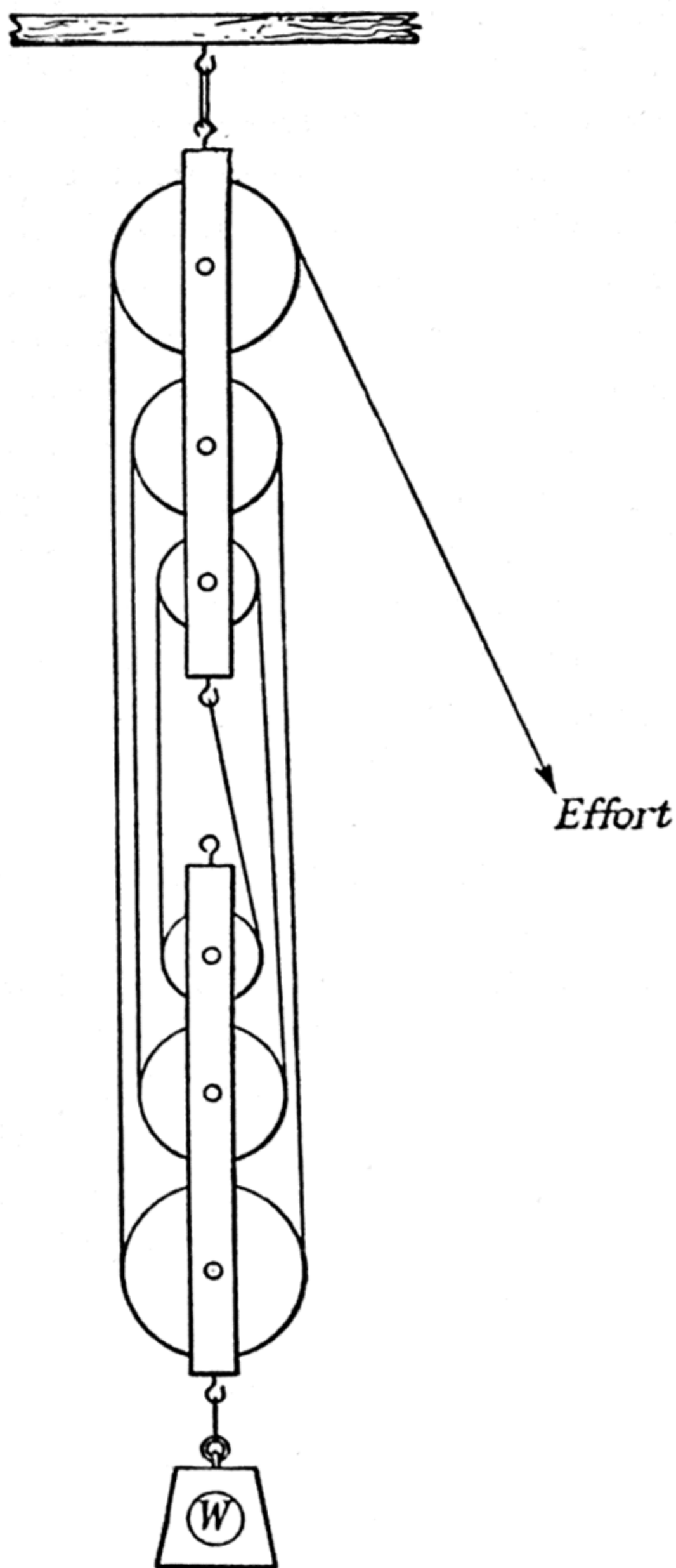
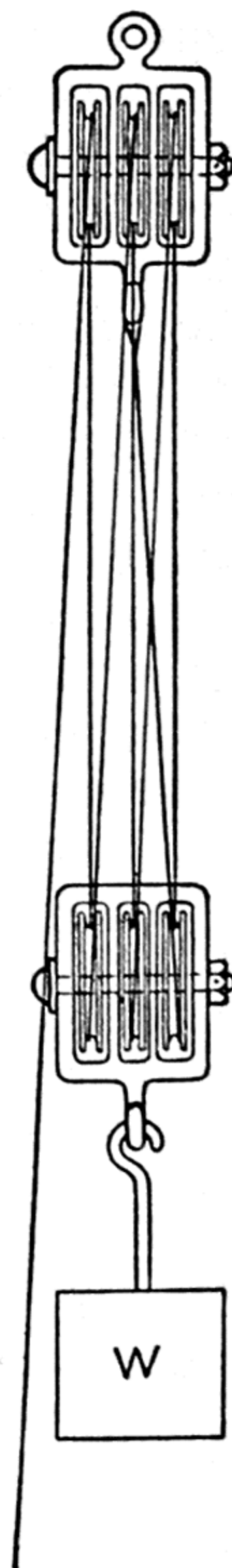


Fig. 137

Fig. 138.  
Block and  
Pulley

### The Principle of Work.

When we lift up a book from a table we have to apply to it a force in an upward direction. The point of application of this force is at the level of the table

to start with, and if we raise the book two feet its point of application is now two feet above the table. The point of application of the force we apply to the book has moved upwards, that is to say, in the direction of the force. When the point of application of a force moves in the direction of the force, the force is said to **do work**. We use the term work here in a much more restricted sense than in ordinary usage. We limit it to **mechanical work**. When we raise the book there is also another force acting on it, namely, the force of gravity, the weight of the book. The point of application of this force alters also, but in the opposite direction to that of the force, which is downwards. We say that work has been done **on** or **against** the weight of the book by the lifting force.

Work is measured by the **product of the force and the distance its point of application moves in the direction of the force**. That is, if the book weighs 3 lb., the work done in raising it 2 ft. is  $3 \times 2 = 6$  foot-pounds.

If we push the book two feet along the surface of the table, we again do work, this time against the force of friction that is pushing backwards against the book. The force of friction, however, will be considerably smaller than the weight of the book, so that the amount of work done will be much less than before. Notice that this time no work has been done against the force of gravity, for, although its point of application has moved, it has moved only horizontally and therefore not in the direction of the force of gravity, which is vertical.

When we raise a weight by means of a pulley or overcome a resistance by means of a lever, the force or effort that we apply moves in the direction of the force. The effort therefore does work; we put work *into* the machine. But the weight that is lifted, or the resistance that we overcome, moves in the opposite direction to that in which the weight or resistance is acting, so

that work is done on the weight, in the case of the pulley system, or against the resistance, in the case of the lever. This represents the work done *by* the machine, the work that we get out of it. Is there any relationship between the work that we put into a machine and the work that we get out of it? Let us take a numerical example. Suppose we have a lever to which we apply an effort of 24 lb. weight at a distance of 3 ft. from the fulcrum, and let us suppose the other arm of the lever is 1 ft. long; then we have a mechanical advantage of 3, so that the resistance we can overcome is 72 lb. weight. Suppose that the distance the effort moves is 6 in. Now the velocity ratio is the same as the mechanical advantage (assuming that there is no friction and neglecting the weight of the lever), so that

$$\frac{\text{distance moved by effort}}{\text{distance moved by resistance}} = 3,$$

therefore the resistance moves  $\frac{6}{3}$  or 2 in. Now, work done by effort =  $24 \times \frac{1}{2} = 12$  ft.-lb. and work done on resistance =  $72 \times \frac{1}{6} = 12$  ft.-lb.

We see that we have to put just as much work into the machine as we get out of it. This statement, which is true not only for the lever but for all machines, is called the **Principle of Work**. We can easily verify it in the case of a pulley system with a mechanical advantage of 6, by means of which a force of 2 lb. weight raises a 12 lb. weight (fig. 137). When the effort moves 6 ft. the resistance only moves 1 ft., so that

$$\text{work done on the machine} = 2 \times 6 = 12 \text{ ft.-lb.}$$

and

$$\text{work done by the machine} = 12 \times 1 = 12 \text{ ft.-lb.}$$

Many seekers after what is called **Perpetual Motion** have endeavoured to construct machines which would give out more work than was put into them. If this were

possible, then by suitable devices part of the work given out could be put back into the machine to keep it going and the balance would be available to do work outside the machine. If such a machine were once started, it would go on doing useful work for ever — a very attractive proposition, although perhaps it sounds a little too good to be true. Nevertheless, much time, money, and ingenuity have been spent on it in the past, but it is clear from the Principle of Work that all such devices are impossible, because we can never get more work out of a machine than we put into it.

### Efficiency.

In actual practice, the amount of useful work that we get out of a machine is always *less* than that which we put in. In our discussion of levers and pulleys above, we assumed that there was no friction at the hinges or bearings. We can never eliminate friction completely, however, and therefore part of the work done by the effort is used up, not in moving the resistance, but in overcoming friction. For any actual machine, therefore,

$$\text{Work put in} = \text{Useful Work got out} \\ + \text{Work done against friction.}$$

The work done against friction is converted into heat, and so is not merely wasted so far as doing useful work is concerned, but is often a source of trouble owing to bearings becoming overheated. Naturally we endeavour to reduce friction to a minimum.

The ratio of the useful work done by a machine to the work put into the machine is called its **efficiency**,

$$\text{i.e.} \quad \text{Efficiency} = \frac{\text{Work got out}}{\text{Work put in}}.$$

If a machine were frictionless then the work got out would equal the work put in and the efficiency of the machine would be equal to 1. In practice, all machines

have an efficiency of less than 1, their mechanical advantage being less than their velocity ratio. The velocity ratio of a machine depends on the size and arrangement of its parts, and is always the same for the same machine, but the mechanical advantage will vary with the amount of friction in the machine and with the load. The smaller the amount of work required to overcome friction, the more nearly will the mechanical advantage become equal to the velocity ratio.

The fact that the mechanical advantage of a machine is less than its velocity ratio can be easily demonstrated with a pulley system such as that of fig. 137. A weight  $F$  is attached to the free end of the string so that the load  $W$  is slowly raised. The distance  $F$  falls and the distance  $W$  rises are measured, and the work done by the effort and the work done on the load can now be calculated. The former will be found to be the greater, and the ratio of the second to the first gives the efficiency of the machine.

### **The Usefulness of Friction.**

Although in a machine the work we do against friction is wasted, friction nevertheless is very useful in many ways; in fact we should find life very difficult without it. We all know how hard it is to walk on ice and to avoid slipping on it. This is because the friction between our feet and the ice is so small. When we walk forward we push backwards on the ground with our foot. This force acts on the ground, and provided our foot does not slip, friction exerts an equal and opposite force on our foot in a forward direction. This latter force is the one that causes us to move forward. If there were no friction our foot would slip backwards and we should be unable to move forward. An athlete at the start of a race hollows out a little hole for his foot, so that he can push against it with a greater force without slipping and so obtain a more powerful push

forward. In the same way, when we are moving and wish to stop, it is the friction between our foot and the ground, acting backwards this time, that brings us to rest. If this fails us, our body continues to move forward and we fall down. In the same way, friction enables us to pick things up and to hold them in our hand. Have you ever noticed how difficult it is to pick up a piece of wet soap?

### **Lubricants.**

Friction is less between polished surfaces than between rough ones, and between hard surfaces than between soft ones. The commonest method of reducing friction between moving surfaces is by **lubrication**. When a lock or bolt has become slightly rusty it may be impossible to move it, but after the application of a little oil it can be moved with ease. The oil acts as a lubricant, forming a film of liquid separating the two surfaces. The layer of oil in contact with each of the solid surfaces moves with the surface, and we have thus substituted for friction between two solid surfaces friction between two liquid surfaces, which is much less. The friction between two polished metal surfaces can be reduced to  $\frac{1}{1000}$  of its original value by lubrication. For heavy machinery a thick oil or grease with plenty of "body" is used, because a thin oil would be squeezed out, but when the pressure between surfaces is comparatively small a thin oil is used. Friction between two surfaces is greatly reduced if we separate the surfaces by **ball bearings**, for in this way we substitute rolling friction for sliding friction. Graphite is sometimes used as a lubricant for bearings, the particles of graphite probably acting as rollers in a similar way to ball bearings. Graphite is a good lubricant for wood surfaces, and drawers that tend to stick can usually be made to run smoothly by putting a little black-lead on the runners and then polishing them.

## Fluid Friction.

We have seen that solids differ from liquids in that the former keep their shape while the latter will take the shape of any vessel in which they are placed. Nevertheless, although all liquids will move in response to even the smallest force, some of them flow very much more slowly than others. This is because of internal friction between different parts of the liquid, which resists movement of one part relative to another. This fluid friction is called **viscosity**, and decreases when the temperature of the liquid rises. Treacle, for example, is a very viscous liquid at room temperatures but flows quite easily when it is hot. A viscous liquid is hard to stir, because considerable force is required to keep part of it moving while the remainder is at rest, and for the same reason the moving part of the liquid quickly comes to rest when we stop stirring.

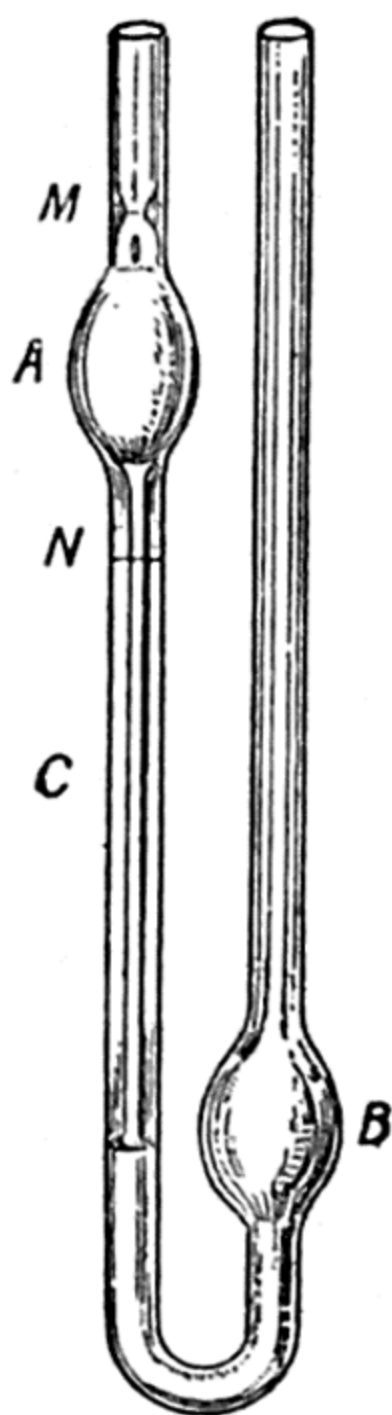


Fig. 139.

A Viscometer

The more viscous a liquid the more slowly it flows through a tube. This fact is made use of in a common form of instrument for the comparison of liquid viscosities. The apparatus consists of a U-tube with two bulbs A and B, joined by a length of narrow tubing C (fig. 139).

A suitable quantity of liquid is introduced into the tube and sucked up until it just fills the bulb A up to the mark M. The liquid is then allowed to flow down the tube C until the level of the liquid in A has fallen to N, the time taken being measured with a stop-watch. The experiment is then repeated with a second liquid and the viscosities of the two liquids will be in the ratio

$\frac{t_1 d_1}{t_2 d_2}$ , where  $t_1$  and  $t_2$  are the times of flow and  $d_1$  and  $d_2$  the corresponding densities. The densities enter into it because the greater the density of a liquid the greater the pressure it exerts on the top of the capillary tube. It is this pressure which causes the liquid to flow down the tube. As the viscosity of a liquid changes very greatly with temperature, it is necessary to surround the apparatus with water in order to keep the temperature constant.

The above method is not suitable for comparing the viscosities of such very viscous liquids as treacle or glycerine, because they flow so slowly. A simple method for such liquids is as follows. Place one of the liquids in a tall narrow cylinder. Put a small ball-bearing ( $\frac{1}{32}$ " ) on the surface and find by a stopwatch how long it takes to fall to the bottom of the liquid. Repeat the experiment, using a second liquid. The time of fall will be longer in the more viscous liquid. A similar effect is seen when small bubbles of air rise to the surface in an inverted jar of liquid.

It is difficult to start a motor-car on a cold day. This is because the oil used as a lubricant has a very much greater viscosity when it is cold, and so becomes "sticky" and "gums up" the bearings.

## Work and Energy.

If we lift a 5-lb. weight from the floor to a table 3 ft. high we have to do a certain amount of work — 15 ft.-lb. But it is possible for us to get work back again from the weight. We could, for example, allow the weight to fall to the floor and drive a nail into the boards, or we could attach a string to the weight, pass the string over a pulley, and, by allowing the weight to fall, we could raise some other body. That is, the weight, while it is on the table, has stored up in it the ability

to do work. This ability to do work is called **energy**. The heavier the weight, and the farther we have raised it — i.e. the greater the amount of work we have done in lifting it — the greater the amount of energy stored up in it. A moving body is able to do work and cause other bodies to move because of its own motion, and the faster the body moves and the heavier it is, the more work it is capable of doing. The 5-lb. weight on the table possesses energy because of its position. This

kind of energy is called **potential energy**. A moving body possesses energy because of its motion — this is **kinetic energy**. These two kinds of energy are closely related, as we can see if we think for a moment of a vibrating pendulum (fig. 140).

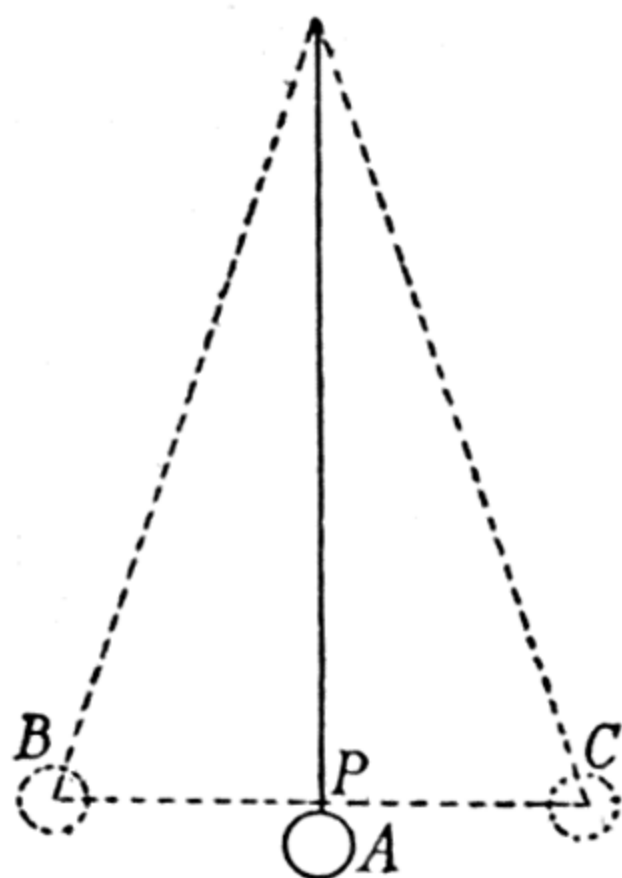


Fig. 140. — Pendulum

When the bob is at B, at the top of its swing, the bob is motionless and has no kinetic energy, but it has potential energy, because the bob can fall the distance PA in coming to the vertical position. As the bob moves from B to A, its potential energy decreases, while its kinetic energy increases. At A, the whole of the energy of the bob is kinetic. Moving from A to C, this kinetic energy is reconverted into potential energy, and so on, energy continually changing from potential energy to kinetic energy and back again as long as the vibrations continue.

Since energy is ability to do work, we may very conveniently measure energy by stating the amount of work that it is capable of doing. Energy, therefore, like work, is measured in foot-pounds. If the bob weighs 5 lb., and the distance PA is 1 ft., then the kinetic energy at A is able to do  $5 \times 1 = 5$  ft.-lb. of work in raising the bob to C. The kinetic energy of

the bob at A is therefore 5 ft.-lb. This kinetic energy has been gained at the expense of the potential energy the bob had when it was in position B. Now, neglecting the very small diminution in angle of swing due to air resistance, C and B are the same distance above A, and at B the bob therefore has 5 ft.-lb. of potential energy, because this can be transformed into 5 ft.-lb. of kinetic energy, which, in turn, can do 5 ft.-lb. of work. We see from this that the potential energy at B is equal to the weight of the bob multiplied by the height to which the bob has been raised above A, i.e.

$$\text{Potential Energy} = \text{Weight} \times \text{Height}$$

to which it is raised. This is, of course, the work we have done in raising the weight, so that the whole of this work is stored up in the weight.

In the switchback or scenic railway, we have another example of the conversion of potential energy into kinetic and back again. The car with its passengers starts from the highest point and, as it gathers speed down the slope, its potential energy decreases, while its kinetic energy increases until, at the bottom, the whole of the energy of the car is kinetic. The car then climbs the next slope, at the top of which nearly all its kinetic energy has been reconverted into potential energy, and so on. Each upward run is shorter than the last because all the time energy is being used up doing work against friction. Not all the potential energy at the top of a given slope is converted into kinetic energy; in going down the slope, part of it is converted into heat. Eventually, as the car comes to rest at ground level at the end of its run, the whole of its original potential energy has been converted into heat. This leads us to suspect that perhaps heat might be a form of energy. If this were so, we ought to be able to convert heat into work. This is what we do in heat engines. We supply heat to the engine, which will then perform

mechanical work, such as lifting heavy weights or driving a train against the forces of friction and wind resistance.

### Heat a Form of Energy.

A rapidly moving object, such as a rifle bullet, is brought to rest when it strikes against a thick metal plate, and the very considerable kinetic energy of the bullet is destroyed. The metal plate feels warm after the impact because the kinetic energy of the bullet has been transformed into heat. Heat, then, is a form of energy, and is capable of doing work.

### QUESTIONS

1. What do you understand by the terms *Force*, *Friction*, *Gravity*?
2. In what respects is friction (a) a handicap, (b) a help, in everyday life?
3. Why is it usually easier to draw a load in a wheeled vehicle than to draw the same load on flat runners? Under what circumstances is it more difficult and why?
4. What is Hooke's Law? How does it apply to the spring balance?
5. How does a compression balance work?
6. What do you mean by the *moment of a force about a point*, and how is it measured?
7. What is the Law of the Lever? If the only weight you had was one weighing  $\frac{1}{3}$  oz., how would you find out whether a letter weighed more than 2 oz.? L.
8. In an ordinary water pump the lever is bent at an angle at the fulcrum and is heavy at the handle end. Explain the advantages gained by these features. L. (part)
9. What is meant by the term *mechanical advantage*? Illustrate your answer by reference to a lever.
10. What do you mean by the *efficiency* of a machine? Why is it always less than 1 for any actual machine?

11. What do you understand by the term *energy*? What reasons have we for believing that heat is a form of energy?

12. Explain how it is possible to lift a heavy weight by means of a considerably smaller one, using one fixed and one movable pulley block. If there are three pulley wheels in each sheaf calculate the force required to raise a weight of 2 cwt., assuming that the movable pulley block weighs 14 lb. and that there is no friction.

13. A 4-lb. weight is suspended from one end of a weightless rod 6 ft. long. What weight must be attached to the other end so that the rod may balance about a point 2 ft. from the 4-lb. weight?

14. Draw diagrams of the following appliances which depend on the law of the lever. In each case mark the fulcrum and the points at which the effort and resistance are applied: (a) sugar tongs, (b) crowbar (used to raise a large stone from the soil), (c) pliers, (d) tin-opener.



## CHAPTER XIII

### THE SKELETON

When a large building is being erected nowadays, we find that first of all a network of steel girders is set up and bolted together to give the necessary strengthening and form a framework for the other parts to be added subsequently. The organs and tissues of the human body are soft, and, in order that they may have sufficient strength and rigidity for our needs, the human body requires a strong and rigid framework. This is provided by means of **bones**. One very important difference between the bony framework of our body and the steel framework of, say, a large cinema, is due to the fact that if our bones were rigidly joined together we should be incapable of movement. Most of our bones, therefore, are jointed in such a way that, while the joints are strong enough to stand very considerable strain, they yet permit of movement in certain directions. A further function of the bony framework of the body, the **skeleton**, is to protect such very delicate organs as the brain, heart, spinal cord, and lungs.

There are altogether over 200 bones in the human body, including 30 in each of the upper and lower limbs. The general arrangement of these bones is shown in fig. 141. We may divide these bones roughly into three classes, according to their shape, (1) long and round — as in the limbs, (2) broad and flat — protecting vital organs of the body, and (3) short and irregular, combining great strength with a limited amount of

movement. We shall consider separately the bones of the skull, of the trunk, and of the limbs.

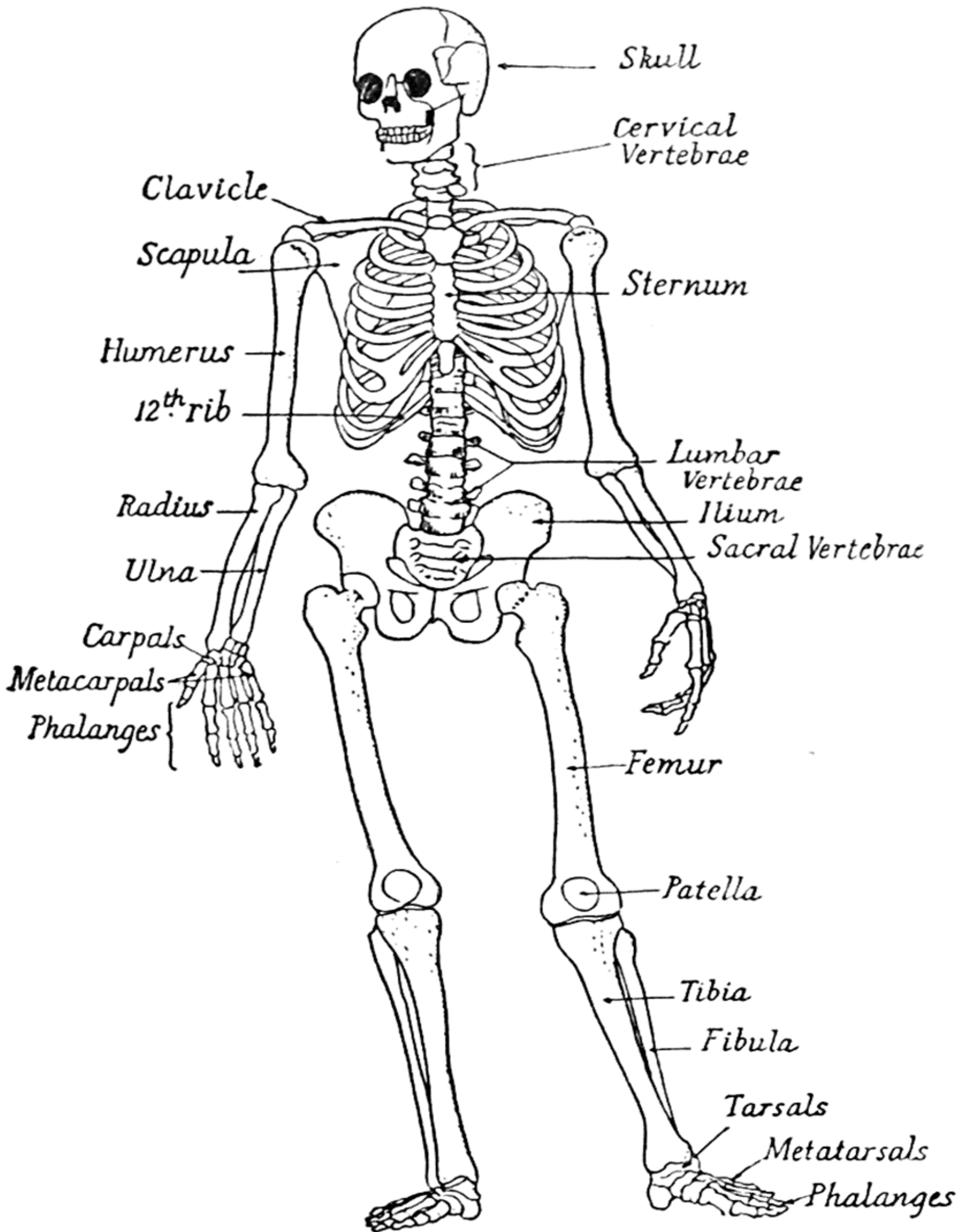


Fig. 141. — The Human Skeleton

The **skull** is composed of a number of flattened bones which are firmly fused together in the adult. In

the child there is still room for the bones to grow. The greater part of the skull consists of a hollow bony box called the **brain-box** or **cranium**, which houses the **brain**. Through a large hole in the base of this box passes the **spinal cord**, and on either side of this hole is a smooth round knob by means of which the head rests on the top of the **vertebral column** (the term backbone, commonly used to denote the vertebral

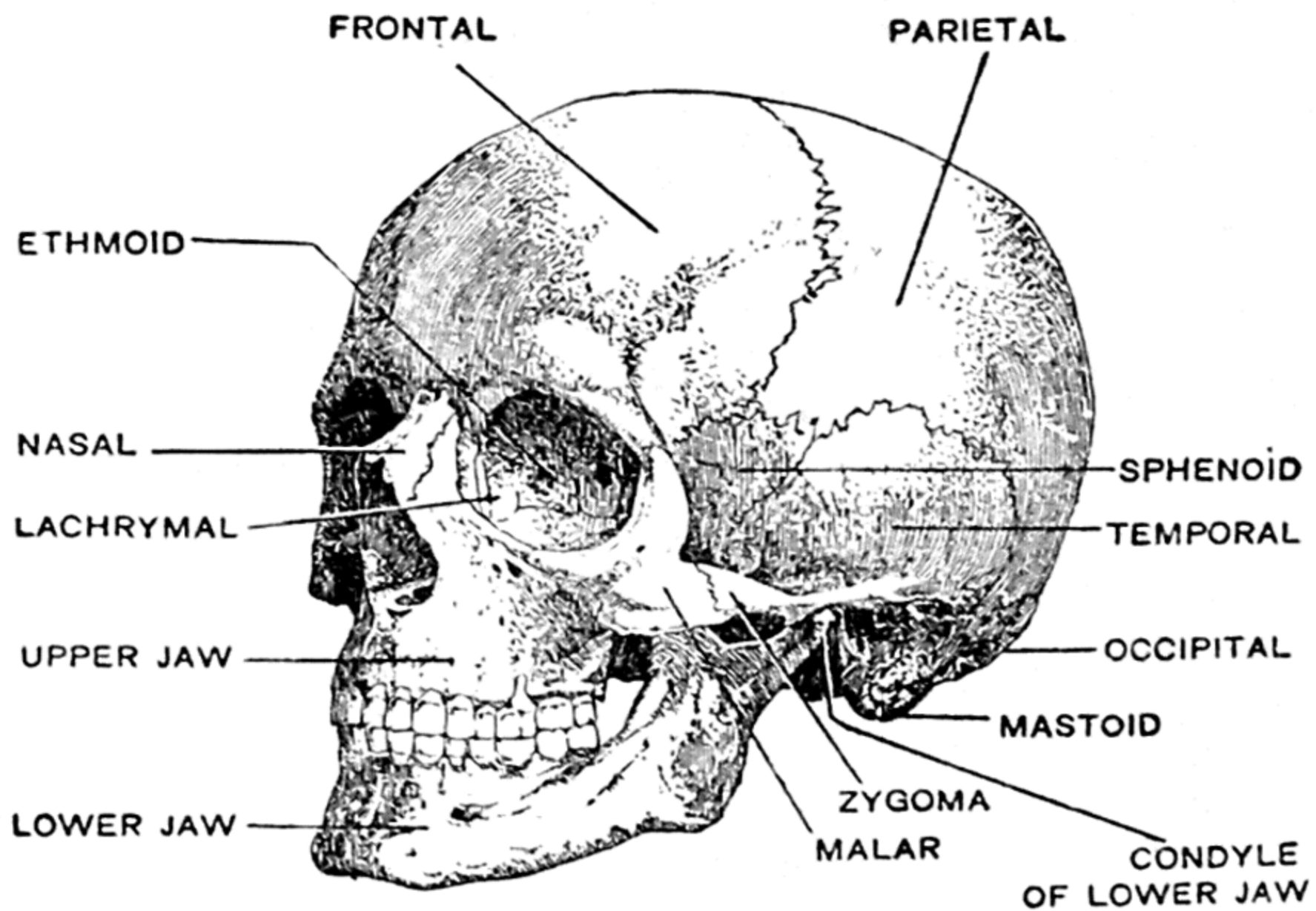


Fig. 142. — The Skull viewed from the left side. The names of the various bones are indicated by the labels

column, should be avoided in scientific description, for the column consists of not one bone but a considerable number). In front of the skull are the bones of the face, including those of the upper jaw. The lower jaw-bone differs from the other bones already mentioned in that it is not fused to adjacent bones, but is jointed or **articulated** to the hind end of the upper jaw in such a manner that it has a power of movement in several directions.

The skull, as we have said, pivots on the top of the vertebral column, which consists of a considerable number of irregularly shaped bones called **vertebræ**

(sing. **vertebra**). These are separated from each other by discs of **gristle** or **cartilage**, an elastic substance which acts as a cushion and shock absorber. The **vertebræ** are joined to each other by very strong **ligaments** in such a way that only a very small movement can take place between successive **vertebræ**. Nevertheless, since there are so many **vertebræ** altogether, the vertebral column as a whole is capable of considerable bending.

Each **vertebra** consists of a round mass of bone in front, with an arch behind enclosing a hole that forms part of a canal running right down the column. This **spinal canal** encloses and protects a long white cord, the **spinal cord**, which, at its upper end, is continuous with the brain. From each arch arise three projections or **processes**, one to each side, and one backwards and downwards. It is this last that we can feel as we rub our hands down our back, and which gives the name to the "spine". Each **vertebra** has also four other smaller processes, two of which interlock or articulate with those of the **vertebra** above it, and two with those of the **vertebra** below it. This arrangement permits of a small amount of movement of

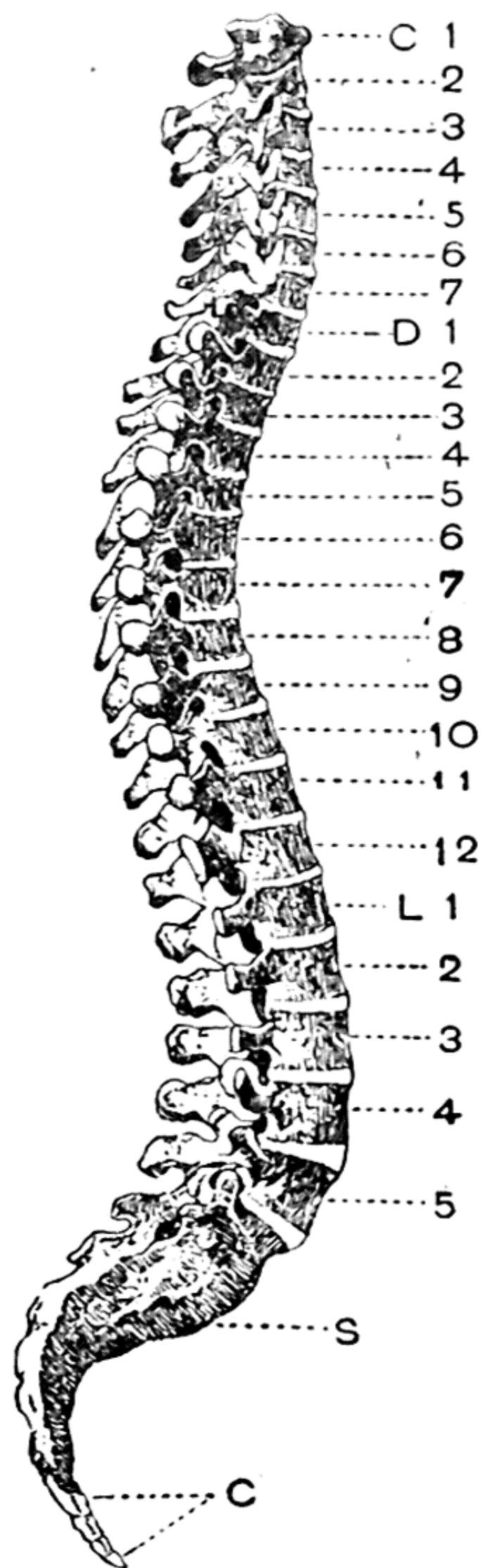


Fig. 143. — The Spinal Column seen from the right side.

C, 1-7 Cervical **vertebræ**.  
 D, 1-12 Dorsal **vertebræ**.  
 L, 1-5 Lumbar **vertebræ**.  
 S, Sacrum.  
 C, Coccyx

one vertebra relative to the next, but prevents it becoming too great.

There are thirty-three vertebræ altogether, seven of

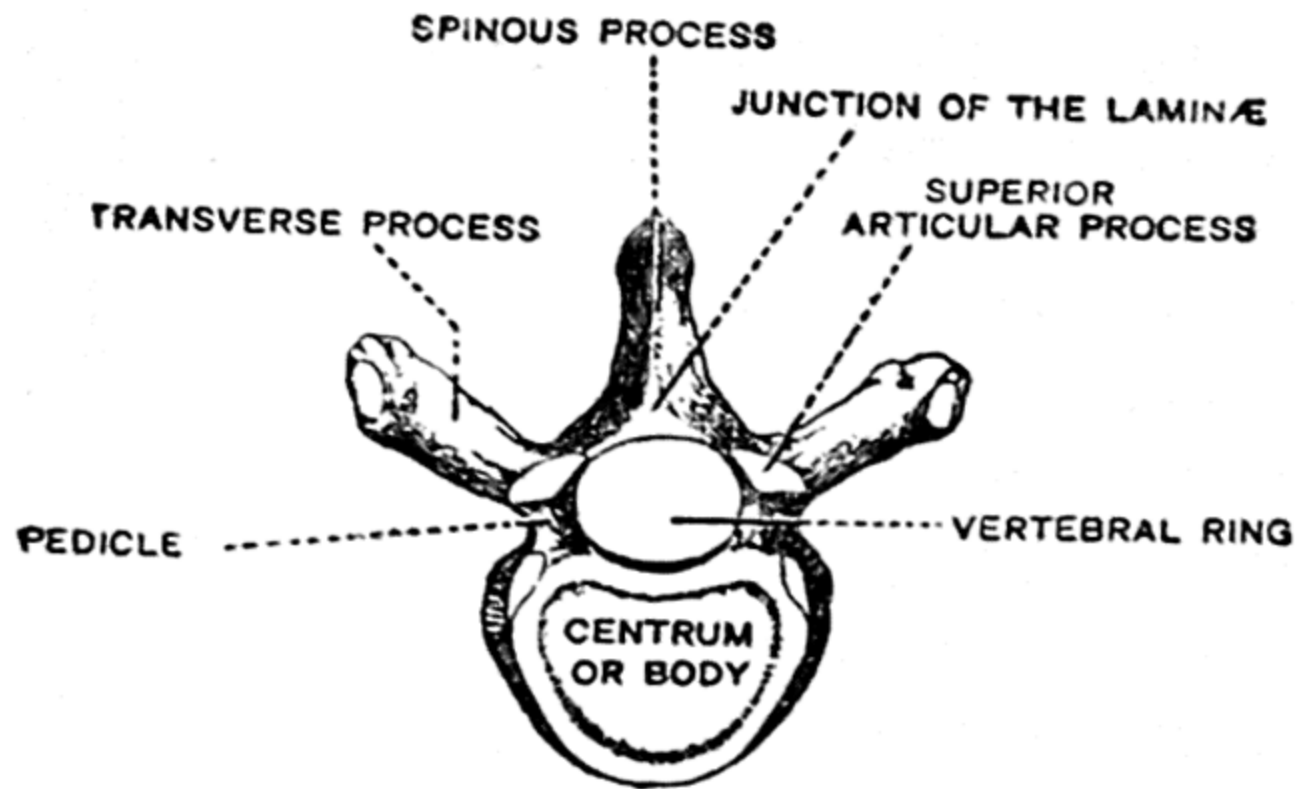


Fig. 144. — A Lumbar Vertebra seen in plan

them in the neck (**cervical vertebræ**), twelve at the back of the thorax (**dorsal vertebræ**), and five at the back of the abdomen (**lumbar vertebræ**). The next

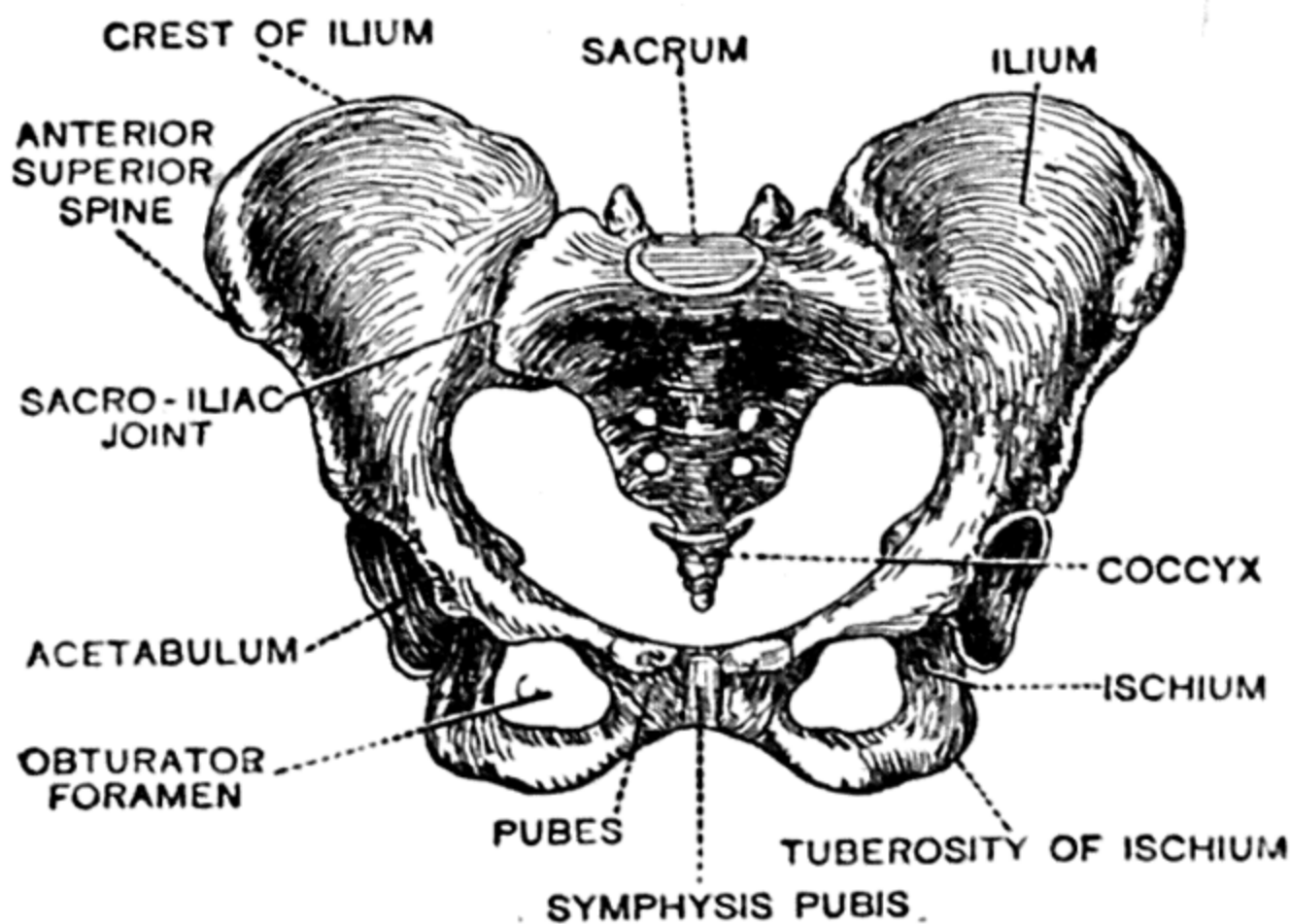


Fig. 145. — The Pelvic Girdle. Note the deep sockets into which the upper ends of the thigh bones fit

five are fused together to form the **sacrum**, joined at each side to the hip-bones, and the four lowest, also fused together, are broad but very short. In many

animals they are longer and more numerous, and form the bones of the tail.

The **thorax** is enclosed in a bony cage, which consists of the vertebral column at the back, the **sternum**, or breast-bone, at the front, and twelve **ribs** at each side. The sternum is a flat bone six to seven inches long, not quite perpendicular but sloping forward so as to increase the volume of the lower part of the chest. Each pair of ribs is jointed to a vertebra at the back, and all except the two lowest pairs are joined by cartilage to the sternum in the front. The two lowest pairs are called **floating ribs**.

The remaining bones of the trunk form two **girdles**, the upper of which consists of the two collar-bones or **clavicles**, at the front, and the two shoulder-blades or **scapulæ** (sing. **scapula**), at the back. The lower or **pelvic girdle** consists of the two hip-bones, irregular in shape, joined together at the front, and joined to the sacrum at the back.

### The Limbs.

The upper girdle of the trunk supports the bones of the arms. The **humerus**, a long and strong bone, is jointed to the shoulder-blade by a shallow ball-and-socket joint that allows it great freedom of movement. Its lower end is joined by a hinge joint to the two bones of the lower arm, the **radius** and **ulna**. The radius is so hinged that it can rotate around the ulna, and thus enables us to place our hand either palm upwards or palm downwards. The wrist and hands are each composed of a number of small bones jointed together in such a way as to allow of considerable movement.

The bones of the leg, supported by the pelvic girdle, are larger and stronger than those of the arm, but follow a similar plan. The **femur**, or thigh-bone, has a deep ball-and-socket joint with the hip-bone, and therefore has less freedom of movement than the

humerus. The femur is hinged at the knee to the **tibia**, or shin-bone, and to a smaller bone at the back of the tibia called the **fibula**. The knee-joint is protected at the front by a rounded bone called the **patella**, or knee-cap. The bones of the ankle and foot resemble those of the wrist and hand. Thus the four fingers and the four smaller toes have each three bones (**phalanges**), while the thumb and the big toe have each two phalanges. The bones of the foot, however, are held together more closely and by stronger ligaments than those of the hand and, consequently have much less power of movement.

We may consider the two girdles and the limbs associated with them as attached to the remaining, or **axial**, part of the skeleton, consisting of the skull, vertebræ, and ribs.

### **Bones.**

The long bones of the body, such as the humerus and femur, are all slightly curved in the direction of their length, and this renders them somewhat "springy", and better able to withstand severe jolts. Bone is surprisingly strong, twice as strong as oak, for example, and a cubic inch of bone can withstand a force of 5000 lb. weight. The forces which bones have most frequently to withstand are bending forces. For a given weight of material a hollow tube is better able to withstand bending than a solid rod of the same substance. It is for this reason that the frame of a bicycle is made tubular. Bones subject to bending strains are hollow also, the inner portion containing fat called **marrow**, and the outer portion consisting of a hard white substance.

Bones are composed of earthy substances, mainly calcium phosphate with a little calcium carbonate, and of animal matter in the ratio of two to one (in adults). They owe their elasticity to the latter; if this is removed by boiling them with water for some hours, they



X-RAY PHOTOGRAPH OF A HAND

Notice the small, flattened bones of the wrist, and the more elongated bones of the hand and fingers

[illegible]

become white and brittle. The animal matter dissolves in the water, and is called jelly or **gelatin**. Bones are used for making soup on account of the gelatin they yield.

**EXPERIMENT 61.** — Weigh a fresh bone and leave it in a large quantity of dilute (10 per cent) hydrochloric acid for a fortnight. Remove the bone from the acid, wash it with water, dry and weigh it. The bone will be found to have lost two-thirds of its original weight, all the calcium phosphate and carbonate having been dissolved by the acid. The remaining substance is soft and easily bent.

## Joints.

As we have seen above, the bones of the body are jointed together in different ways. Some, e.g. the bones of the skull, are so fused together that no movement is

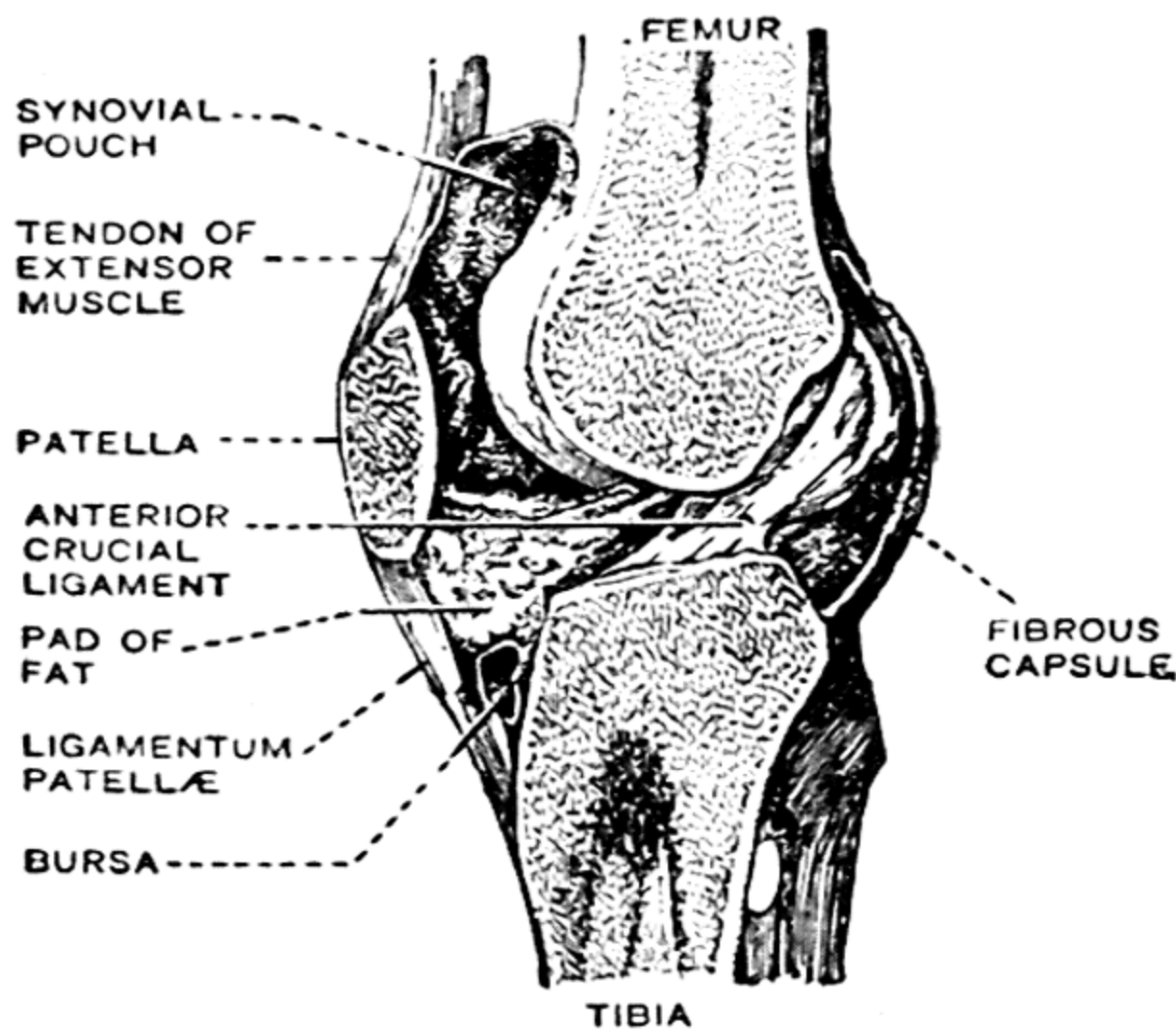


Fig. 146. — Section through Knee Joint

possible. In the spinal column the individual vertebræ are able to move a certain amount on their cushions of cartilage. Hinge-joints, such as the elbow, permit of a larger movement, and ball-and-socket joints, such as the shoulder, give the greatest freedom of all. The surfaces

of the bones at the freer joints are smooth, rounded, and covered with a thin layer of elastic cartilage. The whole joint is enclosed in a loose bag — the **joint capsule** — consisting of a tough membrane, the inner wall of which secretes a fluid that acts as a lubricant.

### **Muscles.**

The movable bones of the body function as levers, and the forces that cause them to move are the pull on them of various **muscles**. These muscles are under the control of the conscious mind. When we are sitting comfortably in an armchair and, becoming drowsy, fall off to sleep, our head falls forward on our chest. In sleep the brain loses control of the muscles of the neck that hold the head erect, and, as the centre of gravity of the head is a little in front of its pivot on the vertebral column, the pull of gravity causes the head to fall forward.

In order that a man may stand upright a large number of muscles are brought into play. Some of these act in such a way as to pull or bend the body forward, and others to pull or bend it backward. As long as the conscious brain is working these two sets of muscles balance each other and keep the weight of the body over the feet, its means of support. The muscles do not need to exert a very great force, for the actual weight of the body is supported by the bones. When the brain ceases to function, as, for example, in a faint, the various muscles, no longer under control, fail to balance each other and the body crumples up.

Long practice causes this control of our muscles to become almost automatic, and we are rarely conscious of it. Nevertheless, like other forms of conscious muscular control, such as kicking a football or making a stroke at cricket, it has to be acquired by practice, and to the infant just learning to stand upright it is a task that demands the whole of its attention.

## Involuntary Muscles.

Besides the muscles under the direct control of the mind, the **voluntary** muscles, there are many others which are **involuntary**; although controlled by the brain, they are not controlled by the conscious part of the brain. An obvious example is the heart. When the heart is beating rapidly after exercise, or in excitement, we cannot cause it to slow down by an effort of the will, and it continues to work with never-failing efficiency even when we are unconscious or asleep. The arteries, veins, and capillaries (see p. 273) are all surrounded by involuntary muscles that regulate the rate at which blood flows through them. When we feel cold, the muscles of the blood-vessels near the skin contract and, as less blood can come to the surface of the body, less heat is lost from the body. The skin, having less blood immediately beneath it, goes white. On the other hand, when we are hot after exercise, the muscles relax and a larger supply of blood comes to the surface of the body, thereby getting rid of the excess heat more rapidly, and at the same time causing the skin to appear red.

## The Vertebrates.

Fishes, birds, and many other animals, besides man, have a vertebral column, but insects, worms, and numerous other organisms have not. We can divide the animal kingdom into two groups, therefore, the **vertebrates**, which possess a vertebral column, and the **invertebrates**, which do not. In all vertebrates we find that the skeleton is built up on the same general plan, although there may be considerable difference in details. Fishes, living in water, do not require so strong a skeleton as a land animal of the same size, since their weight is supported by the water in which they swim.

## Skeleton of the Frog.

Compare the skeleton of a frog (fig. 147) with that of man. The resemblances are obvious, although the relative sizes of many of the bones are different. Note,

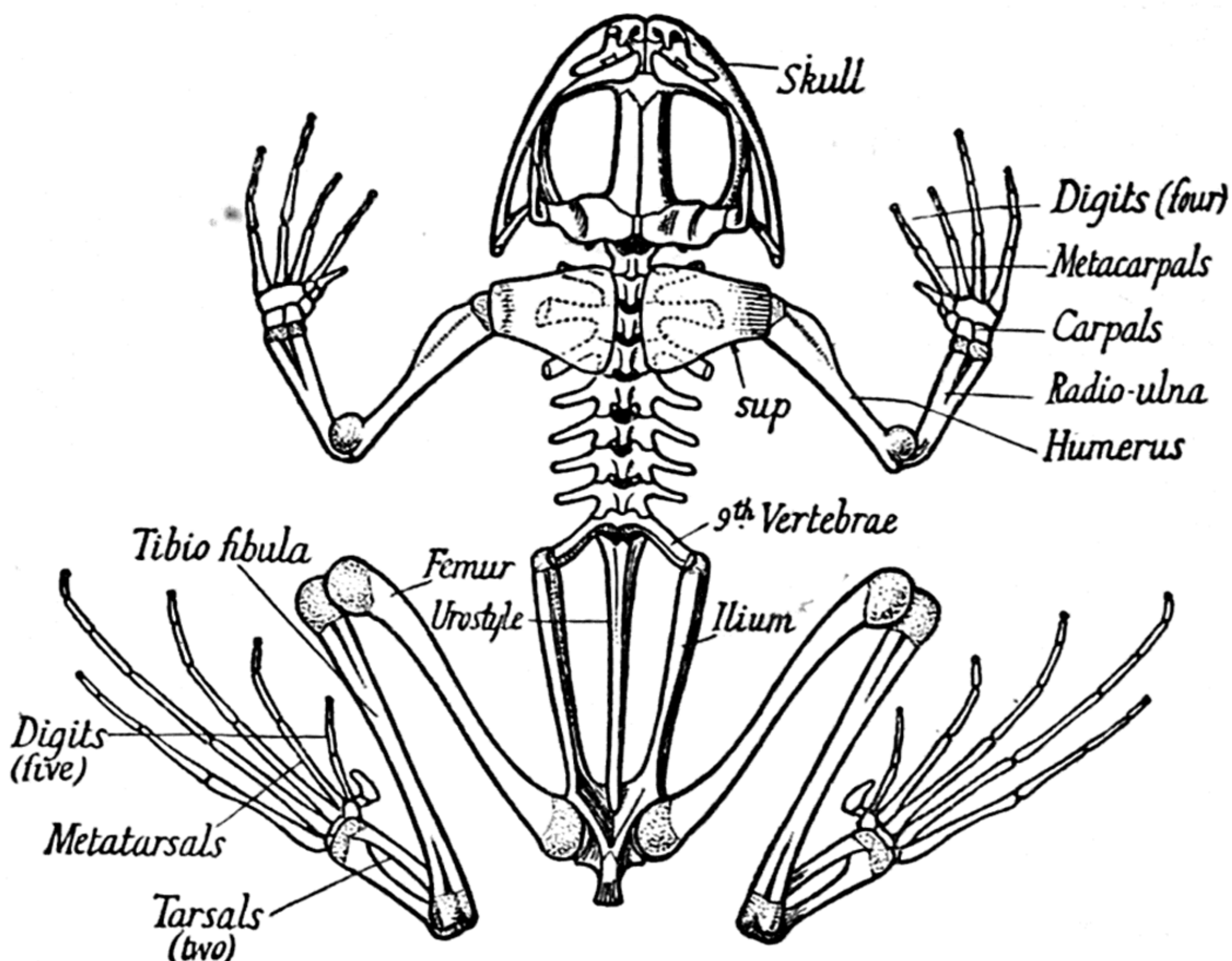


Fig. 147. — Skeleton of Frog. Compare this with fig. 141

for example, the long bones of the ankle and foot (hind limb). Notice that a frog has no ribs, and only nine vertebræ, although it has a single long rod-like bone (the **urostyle**) at the base of the vertebræ.

QUESTIONS

1. In what ways is a hard bony skeleton useful to an animal?
2. Give a brief account of the bones of (*a*) the hand and arm, (*b*) the foot and leg. In what ways do the bones of the hand and arm resemble those of the foot and leg, and in what ways do they differ?
3. Describe the human vertebral column. Why is a broken back or a broken neck usually fatal?
4. Name the types of joint in the body, give one example of each type, and describe one joint. C.W.B. (part)
5. What is the difference between voluntary and involuntary muscles? Why does a man who faints while standing up collapse on the floor?

## CHAPTER XIV

### AIR AND BURNING

What happens when a substance burns? This was a problem to which many incorrect answers had been given before the great French chemist, Lavoisier,\* found the correct solution some 150 years ago. Some substances, such as a candle, or methylated spirits, burn away and leave no residue, and it seems as if they were completely destroyed, while other substances, such as paper, wood, and coal, leave behind only a little ash. Metals, too, can be made to burn. Zinc can be burned in the bunsen flame, and finely powdered magnesium burns with such an intense white light that it is used by photographers as a flashlight powder. When metals burn they leave behind them a powdery ash or calx. A fact about combustion which was discovered at a very early date was that a substance cannot burn unless it has access to a continual supply of fresh air.

**EXPERIMENT 62. — To show that air is necessary for combustion.** Take a bell-jar with a well-greased lower rim and place it over a burning candle. After a short time the candle goes out. Remove the glass stopper of the bell-jar and quickly insert a burning taper. The taper is extinguished.

The fact that combustion cannot take place in the absence of air is used in fire-fighting. When sand is thrown on to flames it forms a layer on top of the burning material, and by preventing the access of air stops

\* Antoine Laurent Lavoisier, born 1743, and executed in 1794 during the French Revolution, despite his eminence as a scientist. The court that condemned him declared that "*La République n'a pas besoin de savants*".

any further burning. Again, when a person's clothing catches fire he should roll over and over on the floor as, when his clothing comes in contact with the floor, it is deprived of its supply of air and thereafter ceases to burn. In laboratories it is usual to keep a large "fire-blanket" which can be thrown round a person on fire to prevent access of air. Fire-extinguishers work on the same principle. Pyrene extinguishers contain a liquid called carbon tetrachloride. When this liquid is squirted on to the flames the heat converts it into a very heavy vapour that remains in contact with the burning surface and excludes the air. Other types of extinguisher generate a heavy gas called carbon dioxide (p. 260) which acts in a similar manner. Unfortunately, the heat generated by a fire produces convection currents (p. 62) that tend to carry even a heavy vapour upwards. This difficulty is overcome in an ingenious manner in foam extinguishers. In these the escaping carbon dioxide is forced through a liquid which forms tough-walled bubbles around the gas. The foam thus produced clings tenaciously to solid surfaces. Water will usually put out a fire, partly by removing access to air and partly by cooling down unburnt material and thus preventing it reaching its **ignition point**. Every inflammable substance requires to be heated to a certain minimum temperature before it will catch fire or ignite. But water is useless in certain cases, for example with oil and petrol fires, for these substances do not mix with water, and, being lighter, float on top of it.

**EXPERIMENT 63. — To extinguish burning methylated spirit by cutting off the supply of air.** Put 50 c.c. of methylated spirit in a small beaker without a spout and place the beaker in a water bath containing boiling water. After the spirit has been boiling for a minute or two ignite the vapour at the top of the beaker. Now quickly place on top of the beaker a cork mat such as is used to stand hot apparatus on. The flames are immediately extinguished.

**EXPERIMENT 64. — To show that burning petrol cannot be put out by water.** Put 20 c.c. of petrol in an evaporating dish on a tin tray and ignite the petrol by means of a lighted taper. Pour on water. The petrol floats on top of the water and continues to burn. Usually when water is poured on burning petrol the latter is spread over a larger area and thus, being in contact with more air, burns more fiercely than before.

**EXPERIMENT 65. — To show the action of carbon tetrachloride as a fire extinguisher.** Ignite 20 c.c. of petrol as in the previous experiment and then pour on about 25 c.c. of carbon tetrachloride. The flames are extinguished.

**EXPERIMENT 66. — To show that when phosphorus burns in air a part of the air is used up.** Place an inverted crucible lid on a cork bung and float the bung on water in a trough.



Fig. 148. — Apparatus to show that when phosphorus burns in air, a part of the air is used up

Take a bell-jar and stick a piece of paper on the outside of it. Take a piece of yellow phosphorus a little larger than a pea, and put it on the crucible lid. (Note: Phosphorus is exceedingly dangerous, for it ignites even when wet at as low a temperature as  $30^{\circ}\text{C}$ ., i.e., below body temperature, and causes serious burns, which are very slow to heal. It is also very poisonous.) Put the bell-jar over the crucible lid and bung and mark the level of the water on the paper. Warm a glass rod by passing it quickly once or twice through a bunsen flame. Insert the rod into the bell-jar and touch the phosphorus with the warm end. The phosphorus will ignite. Quickly

remove the rod and replace the stopper of the bell-jar. The jar fills with thick white fumes and, after a while, the phosphorus goes out. Allow the air inside the jar to cool. The water will be found to have risen a considerable distance up the inside of the jar. Mark the new level of the water. Evidently a part of the air has been used up. Insert a lighted taper. It goes out; the remaining gas does not support combustion. The proportion of air used up can be found roughly by comparing the height the water has risen with the height of the top of the

jar above the water outside, or, more accurately, by removing the jar, inverting it, and finding the volume of water required to fill the jar up to each of the two marks. The volume used up is found to be rather less than  $\frac{1}{5}$  of the original volume.

We see from the above experiment that a part of the air has apparently vanished. What has become of it? The following experiment will give us a clue.

**EXPERIMENT 67. — To find the change in weight when magnesium burns.** When we burn a strip of magnesium a lot of white fumes escape. In order that we may weigh the whole of the ash produced we shall burn our magnesium in a crucible fitted with a lid. Weigh a clean dry crucible and lid and put in it about 6 in. of bright magnesium ribbon broken up into small pieces. Should the ribbon be tarnished scrape off the surface film with a penknife. Weigh the crucible and lid again, and thus find the weight of the magnesium used. Now proceed to heat the crucible, very gently at first and then more strongly. In order to allow air to get to the magnesium remove the lid with crucible tongs from time to time, first taking away the bunsen, and replace the lid as soon as the magnesium begins to burn rapidly. Continue heating for some minutes after all further action appears to have finished. Allow the apparatus to cool, and then weigh it again. Note that there is an increase in weight. In order to prevent damage to the crucible in this experiment it is advisable to put a thin layer of sand at the bottom of the crucible before adding the magnesium.

When magnesium burns in air the residual ash weighs more than the original metal. This is found to be the case also with other metals, such as tin, lead, and iron, although these are more difficult to burn. Where has the increase in weight come from? Remembering our experiment with phosphorus, we might suggest that it was due to a part of the air removed in the process of burning. How is it, then, that there is so little ash left when coal or paper burns, while a candle appears to vanish completely? If we had burned our magnesium in a crucible without a lid a lot of fumes would have escaped, the increase in weight would have been much

less than we actually observed, and there might even have been a loss of weight. In the case of the burning candle the escaping fumes are invisible vapours which can, however, be caught and held by fresh quicklime.

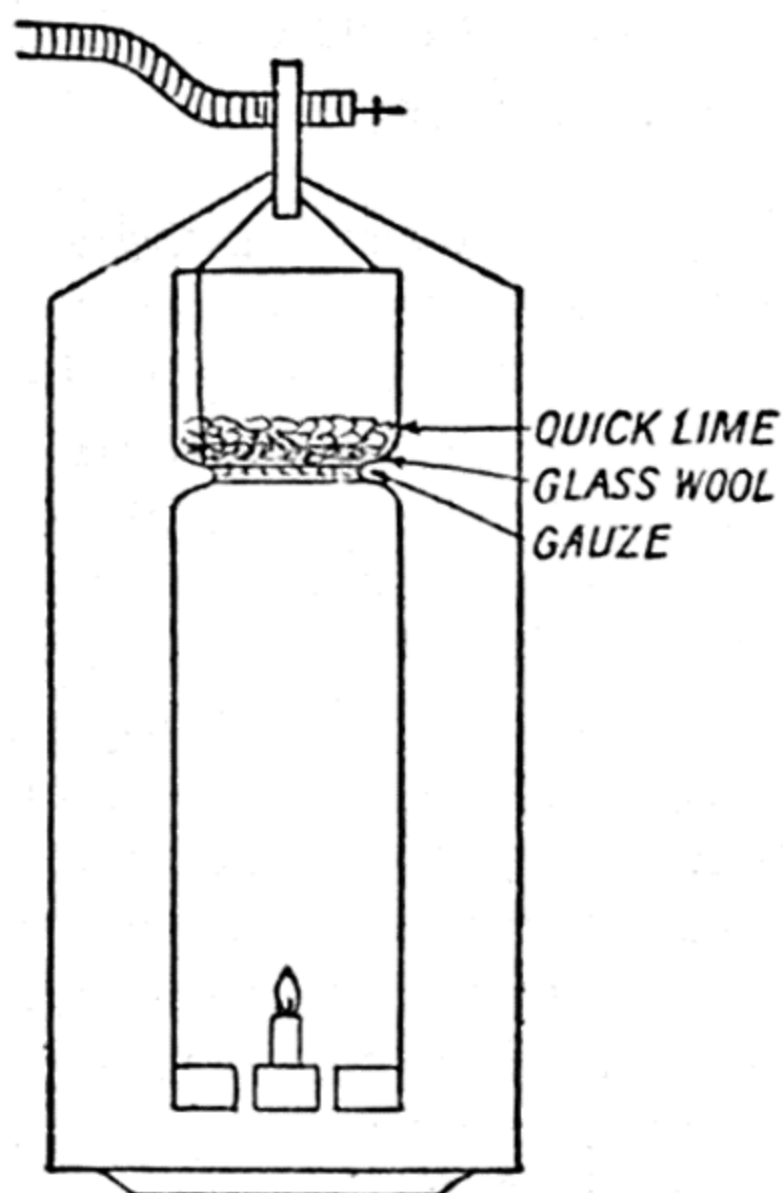


Fig. 149. — To show that there is an increase in weight when a candle burns in air.

EXPERIMENT 68. — To show that there is an increase in weight when a candle burns. Fit a small lamp chimney (fig. 149) with a large cork through which have been bored a number of holes to admit air. Fix a small piece of candle on the cork, and in the upper part of the chimney place a piece of wire gauze on which is a layer of glass wool. On top of the glass wool put a layer of fresh quicklime to absorb the fumes given off by the burning candle. (Why do not the fumes come out through the holes in the cork?) Counterpoise the lamp chimney on a balance in such a way that air can enter through the holes in the cork. Light the candle. As the candle burns away it will be seen that the balance falls on the side bearing the lamp chimney.

To sum up, it is clear from the preceding experiments that when substances burn a part of the air is used up, and that this part unites with the substance burning to form products of combustion that have a greater weight than that of the substance burning. Since when a body burns in a closed space the air left is no longer able to support combustion, it would seem that there are two gases present in air — one able to support combustion and the other not able to support combustion — these gases being present in the proportion of about one to four by volume. The gas that supports combustion is called **oxygen** and the other **nitrogen**.

**EXPERIMENT 69. — To prepare oxygen and examine its properties.** The gas is prepared by heating in a flask a mixture of four parts of potassium chlorate with one part of dry manganese dioxide.\* During the heating the air holes of the bunsen should be almost closed so as to obtain a luminous flame. A wide delivery tube *D* conveys the gas to below the surface of water in the pneumatic trough *T*. Take a number of gas jars *C*, fill them to the top with water, place over each a greased cover plate, invert them, and remove the cover plate under the surface of the water in the trough. The jars remain full of

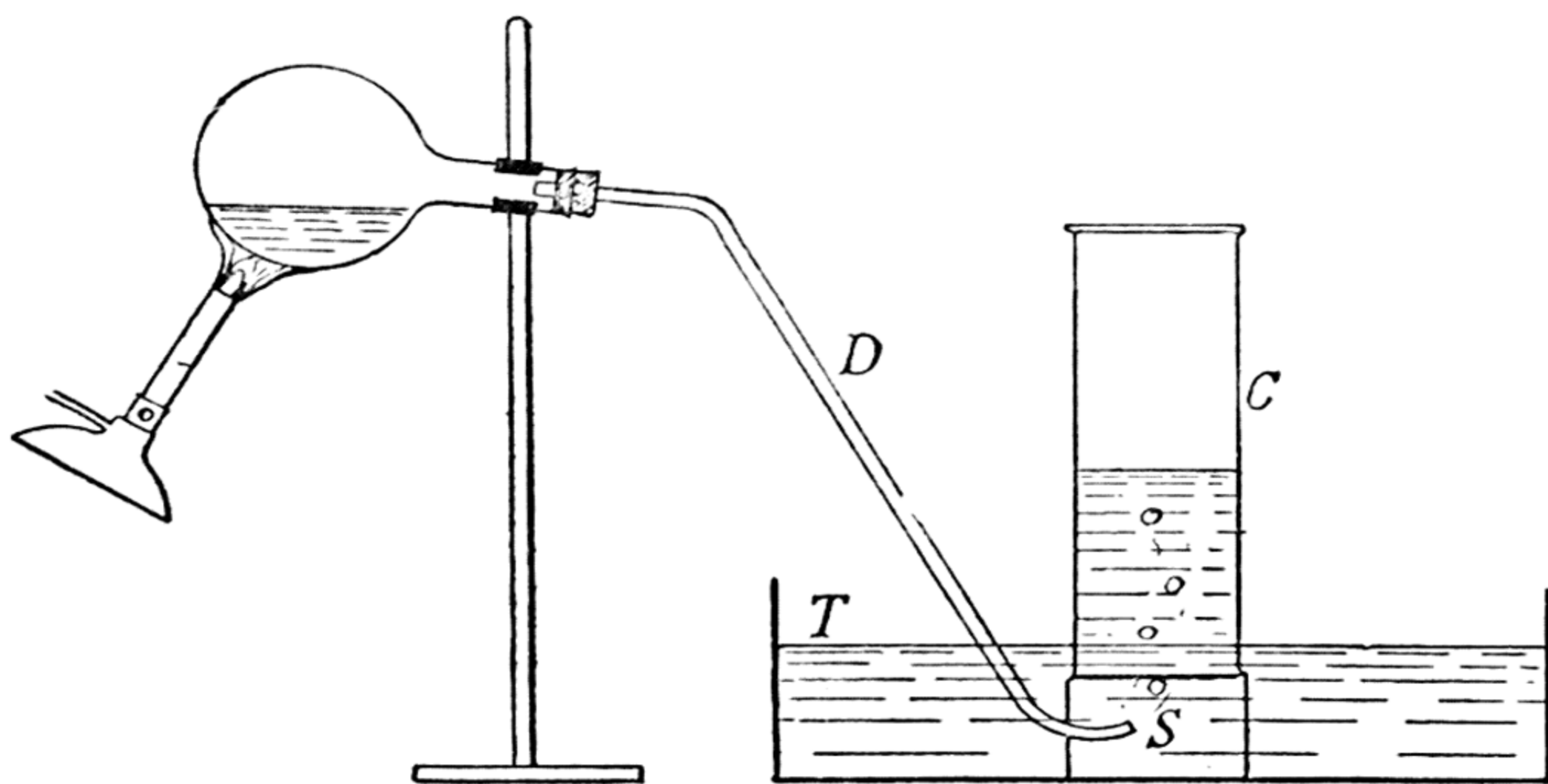


Fig. 150. — Preparation of Oxygen

water. (Why?) Before heating the oxygen mixture place one of the gas jars full of water on the bee-hive shelf *S*. When the oxygen comes off this soon fills with gas, which bubbles up and displaces the water in the jar. When the jar is full of gas slip a cover plate under it and remove it from the trough, replacing it by another jar, and so on, until six or seven jars of gas have been collected. The first jar should not be used for testing, as it contains the air, originally in the flask and delivery tube, that was driven out when the oxygen first came off.

The gas collected is colourless, and clearly is not particularly soluble in water or we should not have been able to collect

\* In view of the serious accidents that have occurred owing to powdered charcoal having been mistaken for manganese dioxide, it is always advisable to heat a gram or two of the oxygen mixture in a hard glass test-tube before carrying out the preparation on a larger scale.

it in the way we did. Slide off the cover glass from one of the jars and smell the gas. It is odourless. Add a little neutral litmus solution and shake it up with the gas. There is no change in colour. Take a wooden splint, light it, extinguish it by shaking it in the air, and then quickly put the glowing end into a jar of the gas. It immediately bursts into flame and burns brilliantly. This is an important test for oxygen; oxygen **relights a glowing splint**.

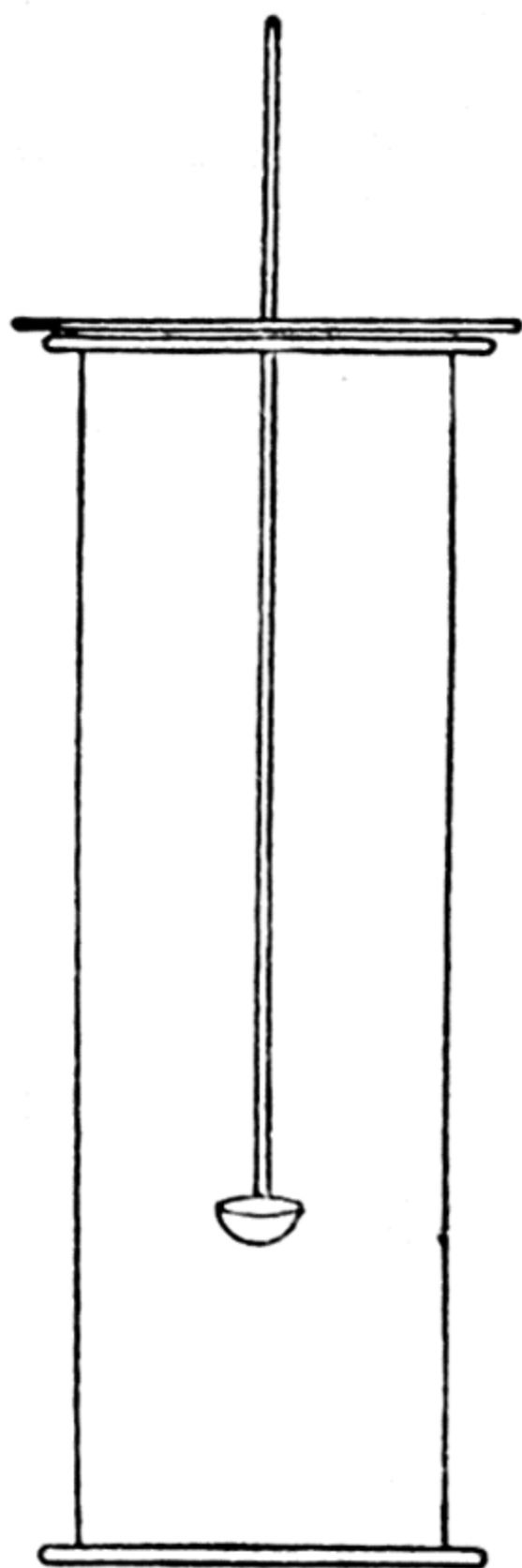


Fig. 151.  
Deflagrating Spoon

Put a little sulphur in a deflagrating spoon, and having ignited it at the bunsen flame put it in a jar of oxygen (fig. 151). It burns much more brilliantly than in air and gives off whitish fumes. Replace the deflagrating spoon by a cover glass, add a little neutral litmus solution and shake it up in the jar. The litmus turns red. Shake up a little sulphur with some neutral litmus solution. The colour of the solution does not change. Substances which cause litmus solution to turn red are called **acids**. When sulphur is burned in oxygen a substance is formed which, dissolved in the water of the litmus solution, forms an acid. Repeat, using phosphorus. This also burns more brilliantly than in air and again an acidic substance is formed.

Hold a couple of inches of magnesium ribbon in a pair of crucible tongs and ignite the ribbon from a bunsen. Plunge the burning ribbon into a jar of oxygen. It burns with an intense white light, too brilliant to look at in comfort, and thick white fumes fill the jar and form a deposit on the walls. Add a little neutral litmus solution and shake up. The solution turns blue. Substances that turn litmus blue are called **bases**. When magnesium burns in oxygen a basic substance is formed. Repeat, using calcium or sodium. Both these burn more brilliantly than in air and yield basic substances.

Cover the bottom of a gas jar containing oxygen with a layer of sand. Tie a little steel wool to a deflagrating spoon with a piece of wire. Make the wool red-hot in a bunsen flame and quickly plunge it into the jar of gas. The steel burns readily.

Put some charcoal (carbon) in a deflagrating spoon, make it red-hot in a bunsen flame and place in a jar of oxygen. The

charcoal burns brilliantly. Add a little neutral litmus solution and shake up. The solution turns red, but not such a bright red as in the case of sulphur and phosphorus. Repeat the experiment, but this time add a little lime-water instead of litmus solution. The lime-water turns milky, although it is not turned milky by oxygen. When carbon burns in oxygen a colourless gas called carbon dioxide is formed, and this gas has the property of turning lime-water milky (p. 262).

## Catalysis.

Although we prepared oxygen from a mixture of potassium chlorate and manganese dioxide we could have obtained it from the potassium chlorate alone. Despite the fact that manganese dioxide contains oxygen, the whole of the oxygen given off comes from the potassium chlorate, and the manganese dioxide is left behind unchanged at the end of the heating. This can be shown by mixing a weighed amount of manganese dioxide with potassium chlorate, using the mixture to prepare oxygen, and then finding how much manganese dioxide is left behind. This can be done by dissolving the remainder of the contents of the flask in water and then filtering off the insoluble manganese dioxide, drying, and weighing it. The manganese dioxide, although unchanged itself, causes the potassium chlorate to give off its oxygen much more readily than it would otherwise do and at a much lower temperature. This is an example of **catalysis**, and the manganese dioxide is called a **catalyst**.

Very many chemical reactions can be speeded up and made to proceed much more easily by adding a suitable catalyst, and this fact is made very great use of in industrial chemistry. In many cases the reaction is so slow in the absence of a catalyst as to be imperceptible. We shall come across further examples of catalysis later.

**EXPERIMENT 70.** — To show the catalytic effect of manganese dioxide in the preparation of oxygen. Take a

test-tube containing some potassium chlorate and heat the latter until it has just melted. At once insert a glowing splint and show that oxygen is not being given off. Heat more strongly. On again testing with a glowing splint oxygen is found to be coming off slowly. Take another test-tube containing potassium chlorate and again just melt it. Add a pinch of manganese dioxide and remove the test-tube from the flame. A glowing splint placed in the tube is relighted and burns brilliantly, showing the rapid evolution of oxygen.

**EXPERIMENT 71. — The catalytic production of oxygen from bleaching powder.** Take a gram or two of bleaching powder in a test-tube and add 10 c.c. of water. Shake up and warm. Show by means of a glowing splint that no oxygen is given off. Add one drop of a solution of cobalt nitrate. Oxygen is given off rapidly and will relight a glowing splint.

We found that when phosphorus burned in air about one-fifth of the air was used up and the remainder did not support combustion. The phosphorus actually goes out before all the oxygen is used up, as it cannot secure the oxygen from every part of the vessel quickly enough. But if phosphorus is left in contact with oxygen it slowly combines with it, giving the same product as when it burns in air. This is called **slow combustion**, and because of this slow combustion it is necessary to keep phosphorus under water. We can obtain a more accurate value for the percentage of oxygen in air as follows.

**EXPERIMENT 72. — To find the percentage of oxygen in air.** Take a long graduated tube, closed at one end. If the graduations do not extend right to the open end, find the total volume by filling the tube with water. Take a long piece of fairly stiff wire, make a loop at one end and put in it a piece of phosphorus rather larger than a pea. Push the phosphorus up the tube on the wire and place the open end of the tube under water. At the end of a week the water will be found to have risen in the tube. Make the level of the water outside the tube the same as that inside before reading the volume, so that the residual gas may be at the same pressure as the original air, i.e. atmospheric. The percentage of oxygen absorbed can now be calculated (fig. 152).

## The Composition of the Air.

Although the residual gas in Experiment 72 will not allow substances to burn in it, it does not consist entirely of nitrogen. It contains small amounts of several other gases, all very inactive chemically like nitrogen itself, and none of which support combustion. The one

present in by far the largest amount is argon and the others are helium (a very light gas used for filling airships — see p. 105), neon (used for the brilliant red advertisement signs),

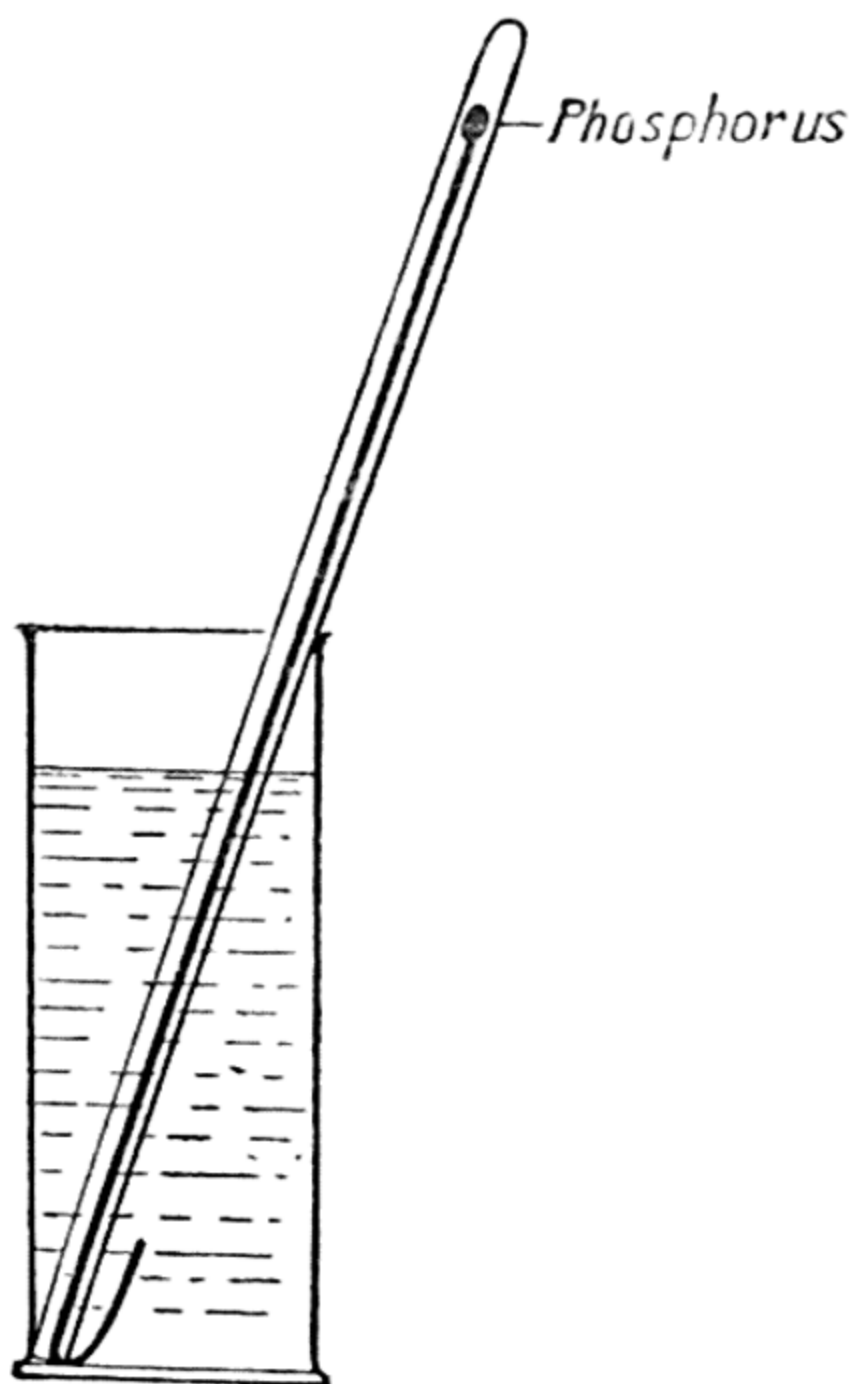


Fig. 152. — Percentage of Oxygen in Air (eudiometer method).

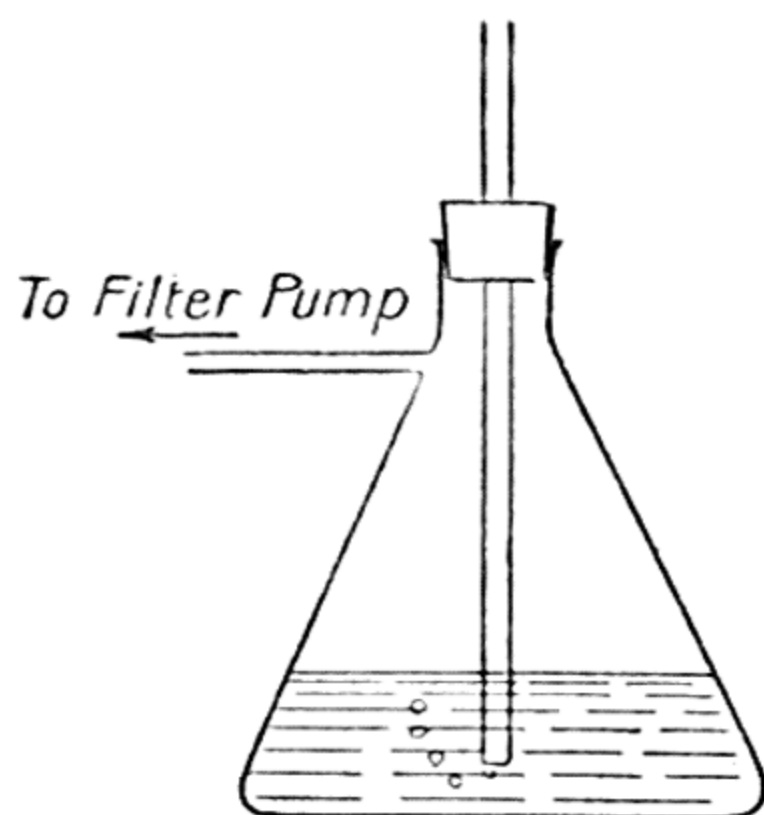


Fig. 153. — Apparatus to show that air contains carbon dioxide.

krypton, and xenon. All these “rare” gases together make up about 1 per cent of the air by volume.

Besides the gases we have already mentioned, air also contains small amounts of two other gases of very great importance to living things. These are water vapour and carbon dioxide. It is obvious from our experiments on hygroscopic substances (p. 162) that water vapour is present in the atmosphere, and the presence of carbon dioxide can be shown by the apparatus of fig. 153. Through the rubber cork of a filter

flask containing lime - water a straight glass tube is passed. The flask is attached to a filter pump and the tap turned on gently. As the pressure of the air in the flask diminishes, the greater atmospheric pressure outside forces air down the glass tube, and this bubbles up through the lime-water in the bottom of the flask. The lime-water soon turns milky, showing the presence of carbon dioxide.

The percentage composition by volume of dry air is as follows:

Nitrogen	..	..	..	78.03%
Oxygen	..	..	..	20.99%
Argon, Helium, etc.	..	..	..	.93%
Carbon dioxide	..	..	..	.03%

The amount of water vapour present in damp air is very variable, but may be as high as 2 per cent. Traces of dust, and also living organisms such as bacteria are usually to be found in air.

## Combustion.

When substances burn in air or oxygen they combine chemically with oxygen to form new substances called **oxides**, containing the oxygen taken in. Thus when carbon burns in air the product is carbon dioxide; sulphur gives sulphur dioxide, magnesium gives magnesium oxide, and so on. As we have seen, the solutions of some of these oxides are acidic to litmus and some are basic. We may note that the oxides of metals, such as sodium and magnesium, are basic, while those of non-metals, such as sulphur, phosphorus, and carbon, are acidic.

## Industrial Preparation and Uses of Oxygen.

For the preparation of large quantities of oxygen a cheaper and more convenient method is used than that

of heating a mixture of potassium chlorate and manganese dioxide. The method involves the liquefaction of air as a preliminary. Although this requires expensive and complicated apparatus, it proves cheaper in the long run when large quantities of oxygen are required. Fig. 154 illustrates clearly how the liquefaction of air is accomplished. Purified air is compressed by the pump

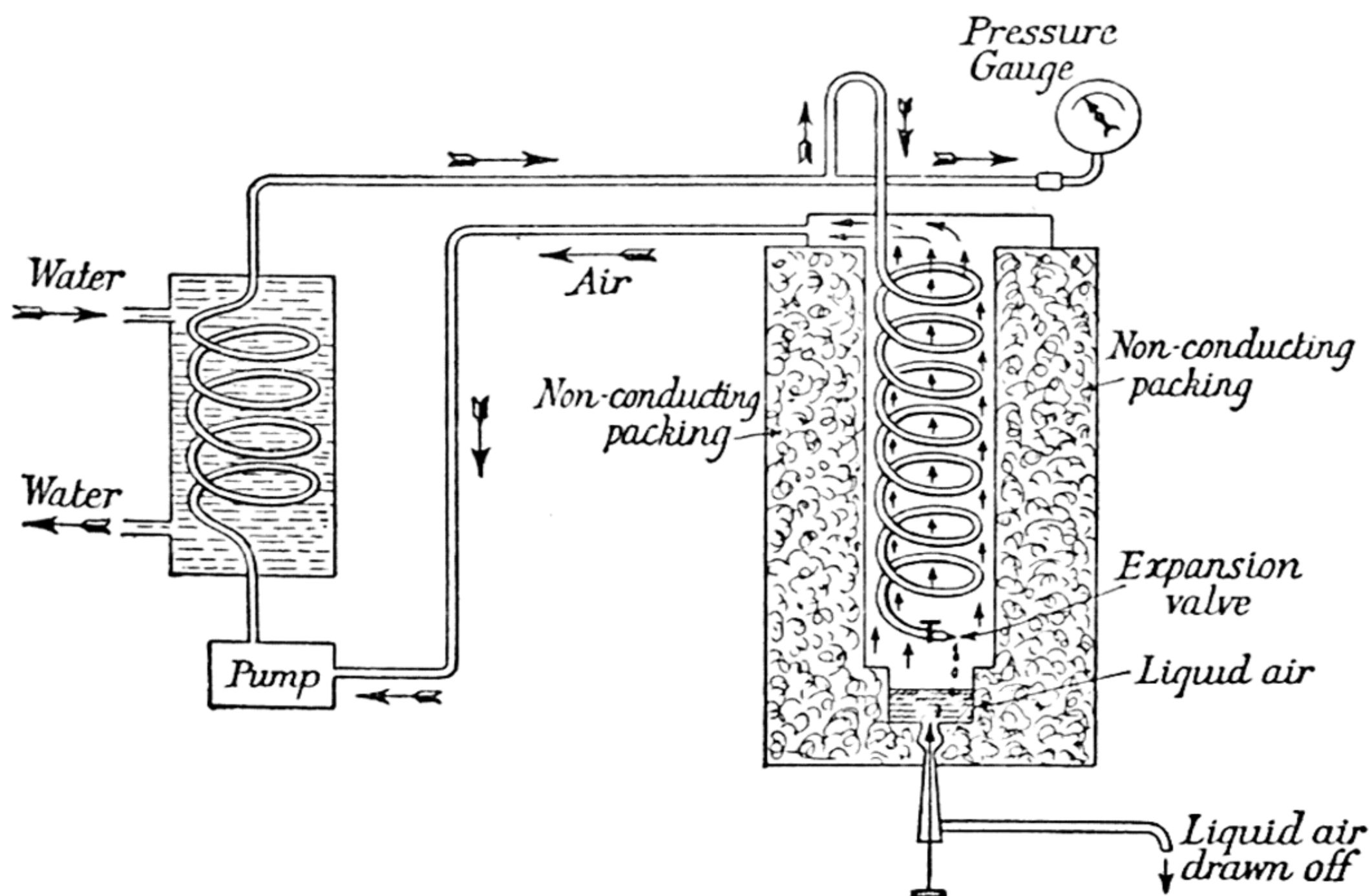


Fig 154. — Diagram to illustrate the method employed for the liquefaction of air

to a very high pressure. Heat is produced during the compression of the gas and is removed by passing the compressed gas through tubes surrounded by cold water. The compressed air is allowed to escape through an expansion chamber, and, as it expands, so it cools. The cold air returns to the pump to be compressed again, but on its way it passes over the tubes bringing the next supply of compressed air. This latter therefore cools on expansion to a lower temperature than the first lot of

air, and in turn cools a further quantity of compressed air. The whole process is continuous, and eventually the compressed air is at so low a temperature when it reaches the expansion valve that the further cooling produced when it expands causes some of it to liquefy.

In the industrial preparation of oxygen the liquid air is allowed to warm up gradually, and the nitrogen, which has a lower boiling-point ( $-196^{\circ}$  C.) than the oxygen ( $-183^{\circ}$  C.), boils off first, leaving behind almost pure liquid oxygen. This is allowed to warm up separately, and the gaseous oxygen so obtained is compressed to 120 atmospheres pressure in steel cylinders, in which it is sold. The rate at which oxygen escapes from such a cylinder can be controlled by means of a valve.

The main use for this oxygen is in connection with the oxy-hydrogen and oxy-acetylene blow-pipes. When hydrogen (p. 237) burns in air it gives a very hot flame, and by mixing the gas in suitable proportions with oxygen in special burners a temperature of  $2000^{\circ}$  C. can be obtained, and such a blow-pipe flame will quickly cut through sheets of iron many inches thick. When acetylene (the gas obtained in cycle lamps by dropping water on to carbide) is used instead of hydrogen an even hotter flame is obtained, and temperatures as high as  $2500^{\circ}$  C. can be reached.

## Flame.

If we light a gas jet we get a **flame**. This flame consists of gas and air rendered incandescent by the heat produced by the combustion of the gas. Solids such as coal, wood, paper, and candle-fat, and liquids such as methylated spirits and petrol, also burn with a flame because these substances, when they are heated, give off gases or vapours which are inflammable. When a piece of coal is put on a fire the heat of the fire soon drives off gas from the coal and the gas burns in flames long before the coal has become red-hot. Coke, how-

ever, has to be heated to a red heat before it will burn, and even then it does not give any flame but burns with a bright red glow. The absence of flame is due to the fact that all the volatile gaseous part of coal is driven off when the coal is converted into coke.

### Candle Flame.

A candle flame, on examination, is found to consist of three zones (fig. 155). Around the wick there is a dark zone of unburned gas (C). If a short piece of narrow glass tubing is held with one end in this zone, the unburned gas can be ignited at the other end of the tubing. Surrounding the inner zone is a large highly luminous zone of partially burned gas (A), and on the outside there is a narrow sheath of almost non-luminous flame (B) in which the gases are completely burned. The third zone is the hottest, although it gives out but little light, so that it is difficult to see.

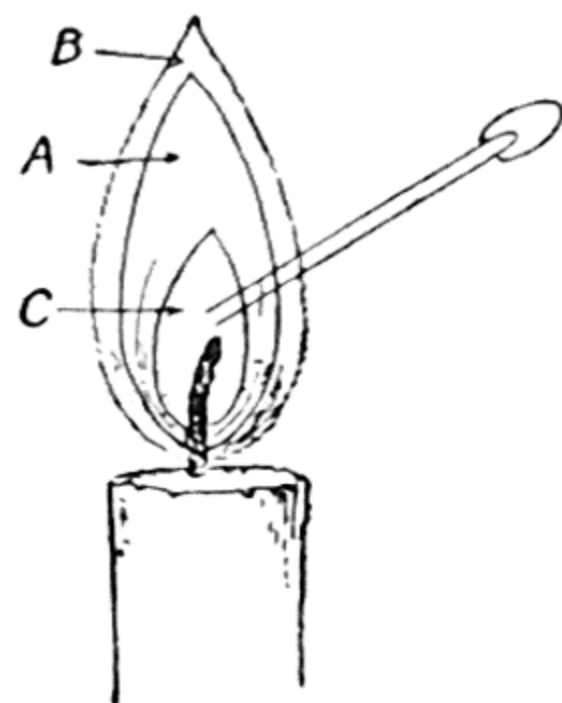


Fig. 155. — Candle Flame

A, Zone of partially burned gas. B, Non-luminous zone of complete combustion. C, Zone of unburned gas.

### The Bunsen Burner.

In the bunsen burner, gas is led into the base of the burner and escapes into the tube at a small hole *b* (fig. 156). The stream of gas issuing at *b* draws in air through the air-holes, and the mixture of gas and air burns at the top of the tube. When the air-holes are closed by means of the collar *c* the bunsen flame is luminous, smoky, and wavering. This flame is similar to the luminous zone of a candle flame, and it owes its luminosity to the same cause, the presence of minute particles of carbon ("smoke") derived from the coal-gas, which consists largely of hydro-carbons (compounds

of carbon and hydrogen). These solid particles are heated to incandescence by the heat liberated during the combustion, and so give out light. When the air-holes are open a non-luminous flame is obtained consisting of only two zones, an inner cone of unburned gas and an outer cone of completely burned gas. The middle luminous zone has disappeared because the additional air drawn in at the air-holes suffices to burn

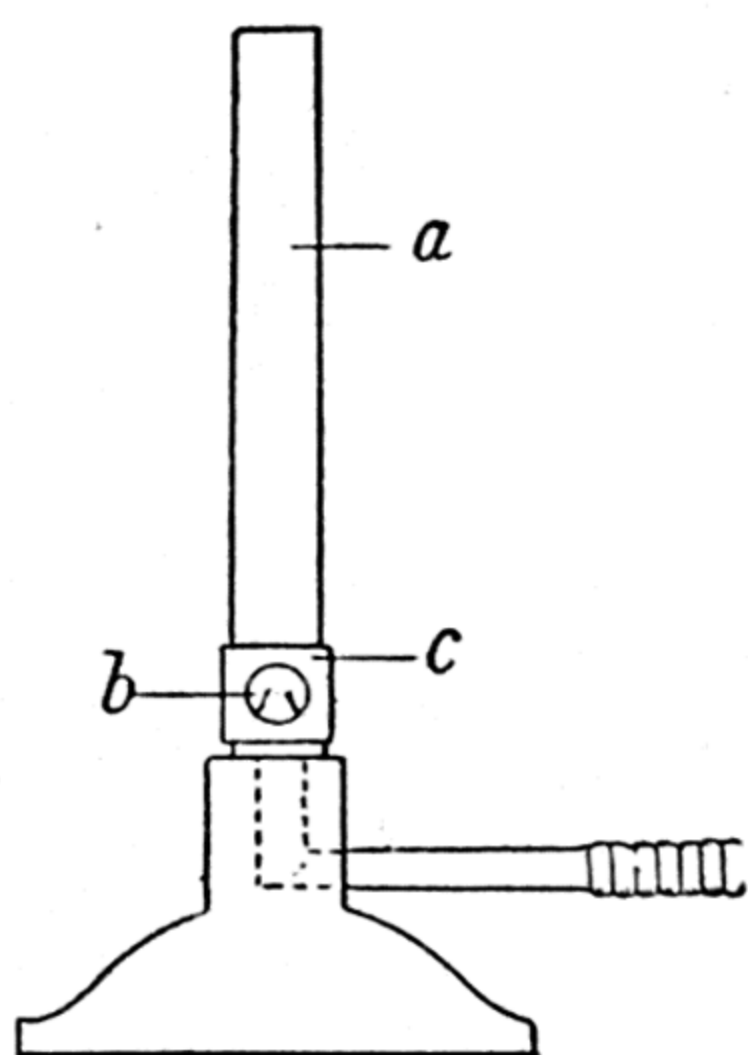


Fig. 156. — Bunsen Burner  
(a) burner-tube; (b) pin-hole;  
(c) collar.

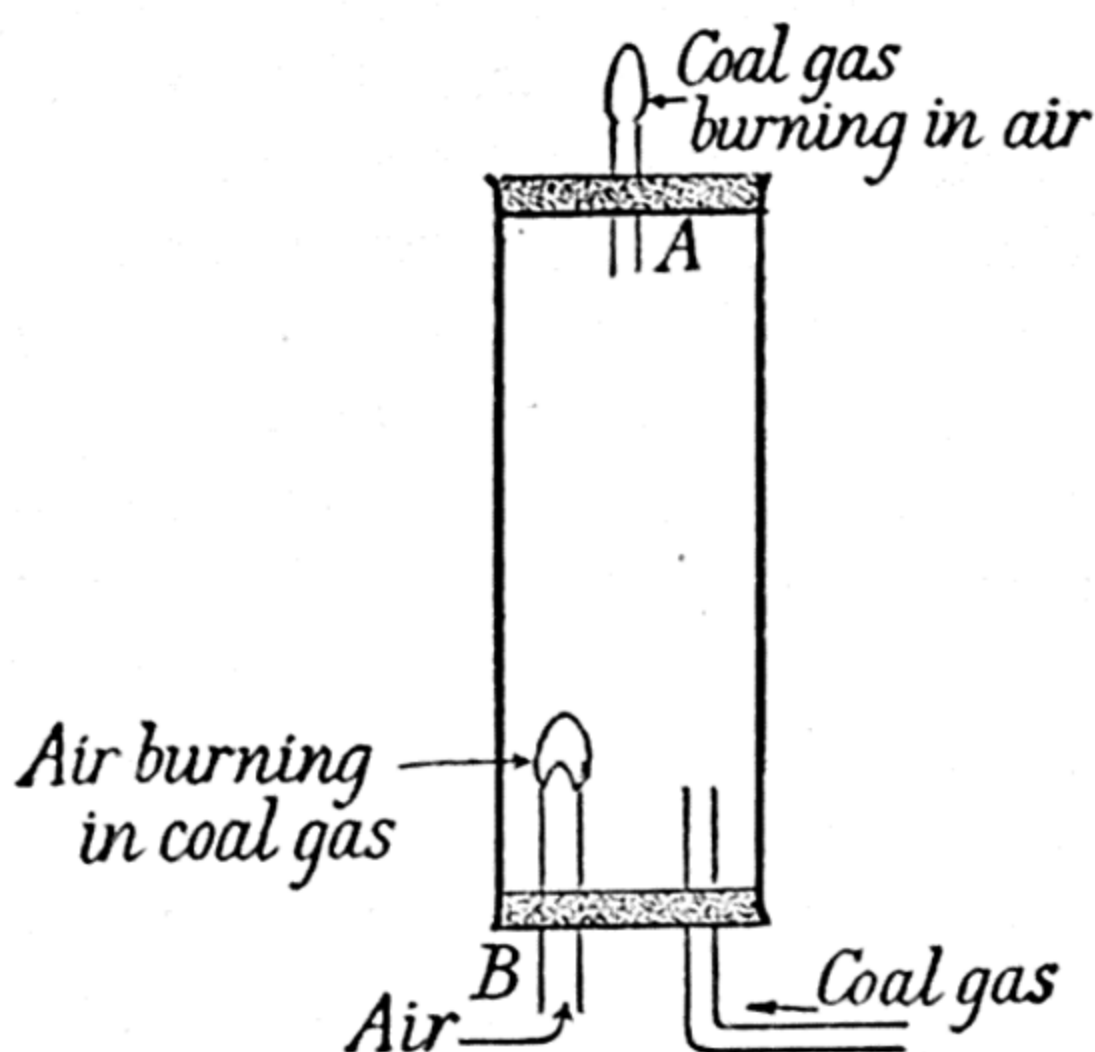


Fig. 157. — Combustible gases are  
also supporters of combustion

up all the carbon before it becomes incandescent. Gas rings and gas fires work on the same principle as the bunsen, a certain amount of air being drawn in through a suitable opening to mix with the gas before ignition.

A mixture of coal-gas and air is **explosive**, i.e. a flame originating in one part of the mixture spreads rapidly throughout the whole mass. The explosion wave from the ignited flame at the top of a bunsen tube travels so slowly, however, that it is prevented from spreading down the bunsen tube by the stream of gas coming up. If the gas supply is turned down this stream may no longer be able to prevent the explosion wave

travelling down the tube, and the bunsen will **strike back**, the gas burning at the pin-hole *b*. It is unable to strike back any farther because, beyond this point, the oncoming gas contains no air for its combustion.

The terms *combustible* and *supporter of combustion* are interchangeable. Coal gas burns in air and, equally, air will burn in coal gas. The apparatus shown in fig. 157 illustrates this. Put a finger over the upper end of the short tube A, turn on the gas and, after about 10 seconds, when all the air has been displaced from the large tube, apply a light to the lower end of the air inlet tube B. Remove the finger from A. The flame at B will move to the upper end of the tube, as shown. Ignite the excess of coal gas issuing at A. To stop the experiment put a finger over the end of tube B and turn off the gas.

## QUESTIONS

1. What happens when a substance burns? Why is air necessary for combustion? Describe an experiment to show the necessity of air for combustion.

2. What is the approximate composition of the air by volume? Describe how you could determine by two methods the percentage of oxygen by volume in the air. Which of your methods do you consider more reliable and why? L.

3. What is meant by *combustion*? Illustrate your answer by reference to the combustion of a candle in air. How can the products of combustion be recognized? L.

4. When a candle burns it ceases to exist in its original form. Describe experiments (*a*) to show what new forms are produced, (*b*) to prove that during burning an increase of mass occurs. L.

5. Give the approximate volume composition of the air. How can the presence of each of the four chief constituents be demonstrated, and what part does each play in everyday life? L.

6. A small piece of phosphorus is placed in a flask full of air and the flask is then tightly corked. If the flask is warmed

slightly, how will the final weight of the flask and its contents compare with the original weight? Give your reasons.

L. (part)

7. What is flame? Describe the structure of (a) a candle flame, (b) a non-luminous bunsen flame.

8. Why does a bunsen burner or gas ring sometimes "strike back" when the gas is turned down?

9. What difference would it make if the atmosphere consisted of oxygen without any nitrogen?

10. Describe some of the methods used to extinguish fire and explain how each method works.

11. Explain what you mean by *catalysis* and give two examples of it.

12. How is oxygen prepared (a) in the laboratory, (b) industrially? Describe some of the industrial uses of oxygen.

## CHAPTER XV

### HYDROGEN AND THE COMPOSITION OF WATER

**EXPERIMENT 73. — The preparation and properties of hydrogen.** Put some granulated zinc in a flask fitted with a thistle funnel and delivery tube (fig. 158) and pour dilute sulphuric acid down the thistle funnel until the lower end of the funnel is under the liquid in the flask. Bubbles of

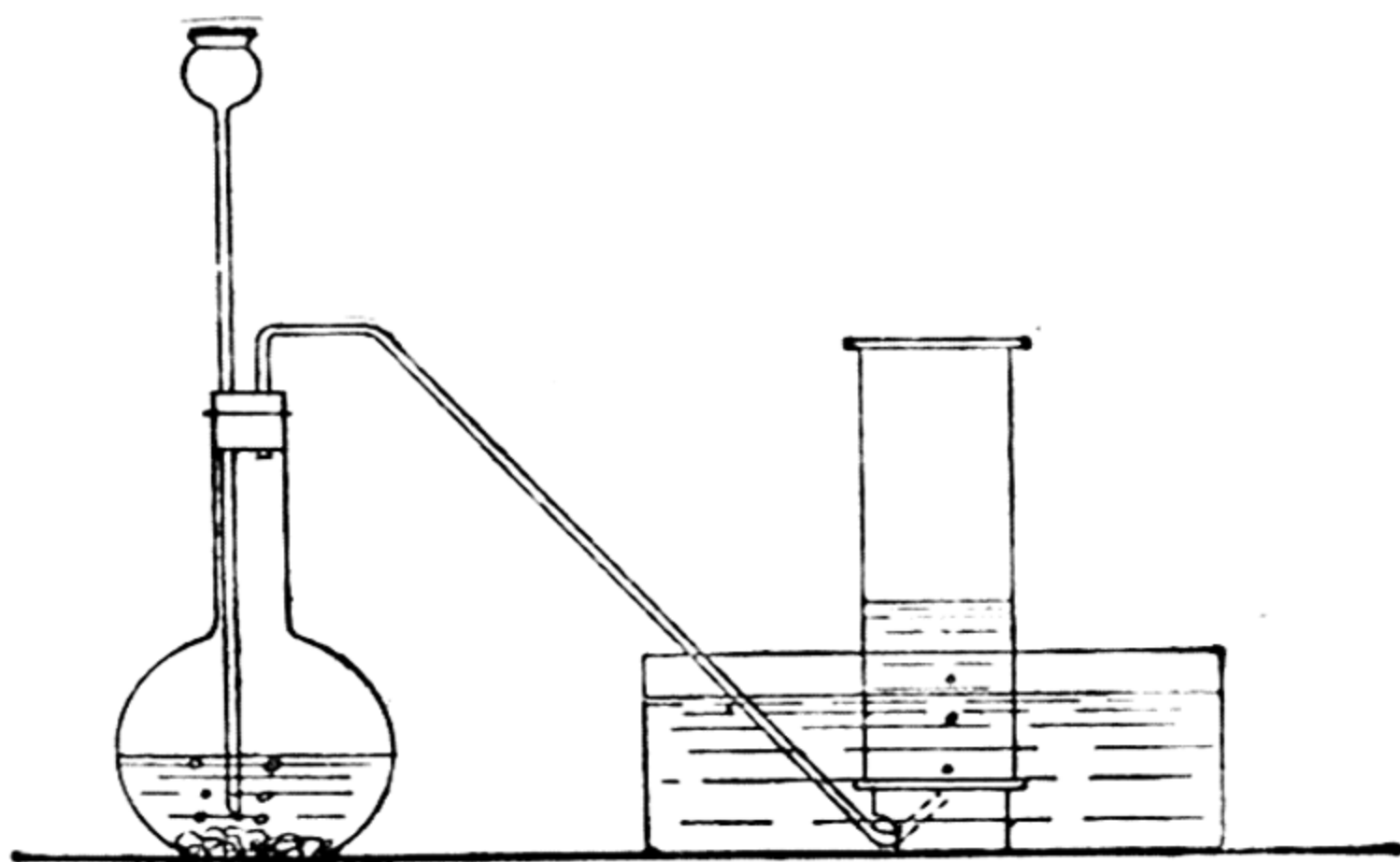


Fig. 158. — Preparation of Hydrogen

gas appear on the surface of the zinc and the contents of the flask become warm. Before collecting jars of the gas in the pneumatic trough fill a test-tube with water and, inverting this under the surface of the water over the bee-hive shelf, fill it with the gas. When it is full put a thumb over the end and bring the mouth of the tube to a bunsen flame. If the gas burns with a loud report further test-tubes of gas must be collected and tested until it burns quietly at the mouth of the tube. This will be when all the air has been expelled from the

apparatus. Hydrogen and air form a very explosive mixture, and a gas-jar-full can cause a serious accident. Collect a number of jars of hydrogen.

The gas is colourless and, since we can collect it over water, not very soluble in water. It is in fact almost insoluble. When

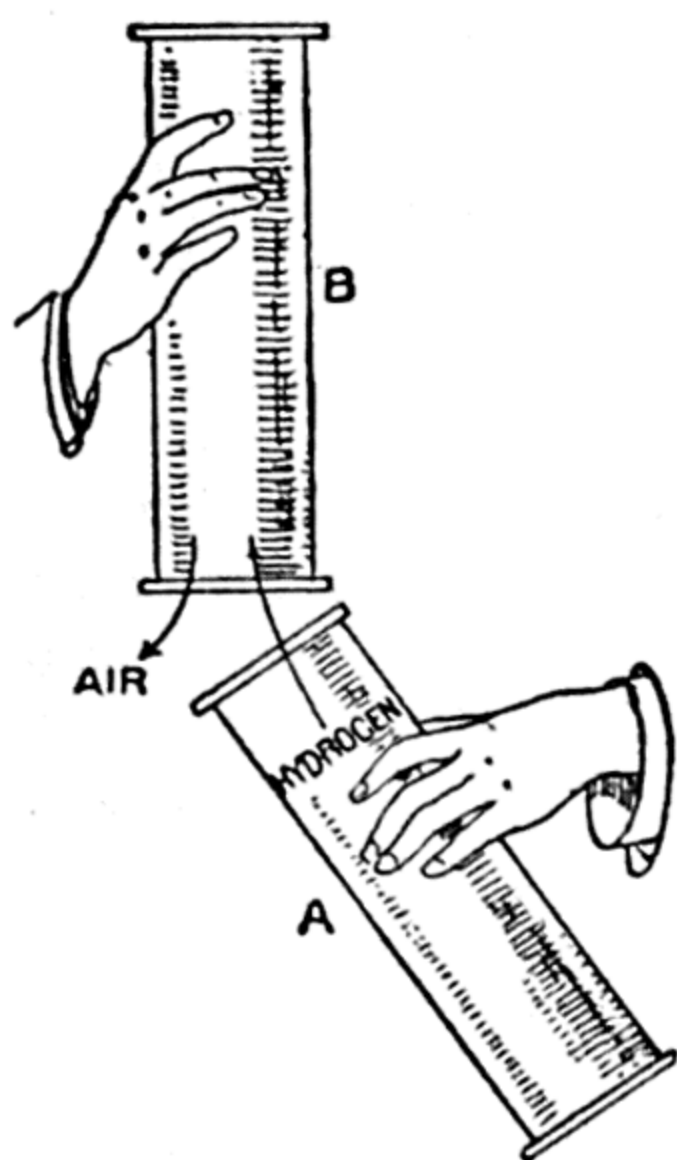


Fig. 159

pure it has no smell but, as usually obtained, it has a slight and characteristic odour. Insert a lighted taper into a jar of the gas. The gas burns at the mouth of the jar but the taper goes out. Hydrogen, unlike oxygen, does not support combustion. Why does the hydrogen burn at the **mouth** of the jar? Add a little neutral litmus solution to a jar of the gas and shake it up.

Hydrogen has no action on litmus, nor has it on lime-water.

Hydrogen is much lighter than air. In fact it is the lightest substance known, having only about  $\frac{1}{14}$  the weight of an equal volume of air. Its lightness can be shown as follows. Take a jar of the gas and a jar containing air. Remove the cover plate from the jar of hydrogen and hold

the jars as shown in fig. 159. After ten seconds test the gas in each jar with a lighted taper. The gas in B burns, possibly with a slight explosion, that in A does not. The hydrogen from A, being lighter than the air in B, has risen above it.

## Chemical Solution.

When we add dilute sulphuric acid to zinc, not only is hydrogen given off but the zinc dissolves. What happens to the zinc?

**EXPERIMENT 74.** — To obtain a solid product of the reaction between zinc and dilute sulphuric acid. Take a few grams of granulated zinc and add a quantity of dilute sulphuric acid not quite sufficient to dissolve all the metal. When the reaction has stopped filter off the undissolved zinc and evaporate the clear filtrate down until a drop of the liquid begins to crystallize when allowed to cool on a watch-glass. Now set the whole of the liquid aside to crystallize.

When it is cool it will be found to contain colourless needle-like crystals of zinc sulphate.

The zinc combines with a part of the sulphuric acid, displacing the hydrogen which forms the other part of the acid. The zinc dissolves in the dilute acid and cannot be recovered from it by evaporation, as we can recover, say, salt or sugar dissolved in water, because it has been converted into a new compound. The solution of a substance in a liquid owing to the formation

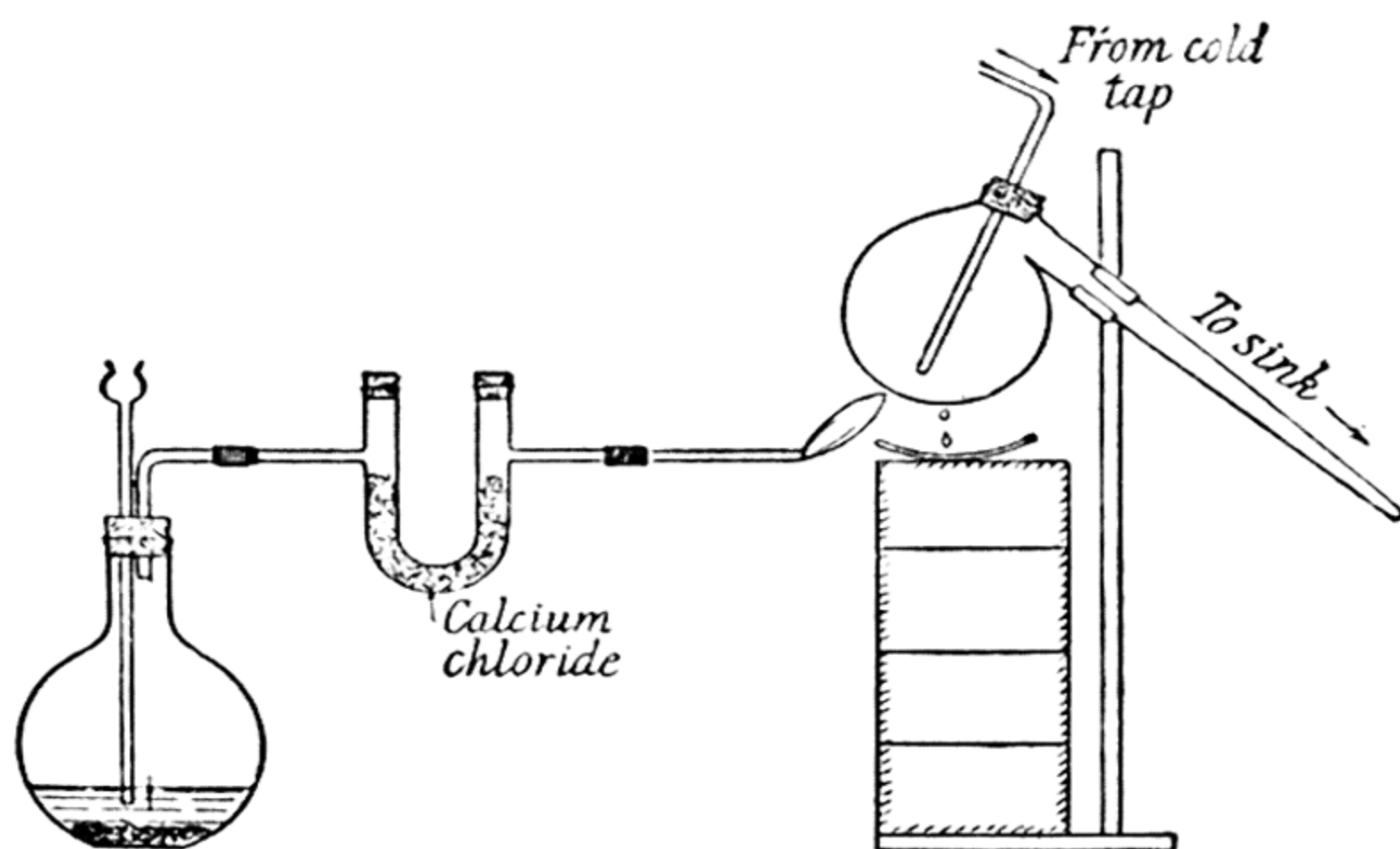


Fig. 160. — To show that water is formed when hydrogen burns

of a new compound is called **chemical solution**. The solution of a substance in a liquid from which it can be recovered unchanged by evaporation of the solvent is **physical solution**, which involves the formation of no new chemical compound.

We have seen in the last chapter that when substances burn in air they combine with oxygen. Since hydrogen burns in air, it would seem likely that hydrogen also combines with oxygen in this process. But the product in this case is apparently an invisible gas. When a hydrogen flame plays on a cold surface small

drops of a colourless liquid form. Perhaps this is the product of combustion which, owing to the heat of the flame, is given off as a vapour when it is not cooled by contact with a cold surface. Let us examine this liquid and find out what it is.

**EXPERIMENT 75. — To determine the nature of the product formed when a hydrogen flame burns against a cold surface.** The apparatus used is shown in fig. 160. Hydrogen is prepared in the usual way. Since it is possible that the liquid formed may be water carried over from the flask by the gas, the latter is passed through a U-tube containing a drying agent, e.g. calcium chloride, before it is led to the fine glass jet. Place a test-tube over the jet and collect a tube-full of the gas by displacement of air. See that the contents of the test-tube burn quietly before lighting the jet. The flame plays against a glass retort through which is passed a stream of cold water in order to keep the outside of the retort cool. Drops of liquid form and drop off on to a watch-glass. The liquid in the watch-glass is colourless and odourless. Add a little anhydrous copper sulphate. It immediately turns blue. The liquid therefore contains water. Is it pure water, water and nothing else but water? This can be shown by collecting a sufficient quantity to determine its melting- and boiling-points. These are found to be  $0^{\circ}$  C. and  $100^{\circ}$  C. respectively. Moreover, on evaporation as in Experiment 38*b*, p. 149, there is no residue. The liquid is therefore pure water.

## The Composition of Water.

If water is formed when hydrogen and oxygen unite, then water must be composed of these two substances, and it should be possible to obtain both hydrogen and oxygen from water. This can be done in several ways.

**EXPERIMENT 76. — To decompose water with metallic sodium.** Take a piece of clean metallic sodium about the size of a small pea and wrap it round with a small piece of fine metal gauze. Drop the gauze into a beaker of water. The sodium, weighted down by the gauze, is carried to the bottom and bubbles of gas are immediately formed. Quickly place a short thistle funnel or small filter funnel over the gauze and invert a test-tube full of water over the top of the funnel

so that the gas formed is collected in the tube. When the action has stopped remove the test-tube, placing a thumb over the end, and test the gas by bringing the mouth of the test-tube to a flame. The gas burns quietly at the mouth of the tube with a yellowish flame, the colour of which is due to the presence of traces of sodium. The gas is hydrogen.

**EXPERIMENT 77. — To decompose steam by heated magnesium.** Place about 0.3 gm. of bright magnesium ribbon

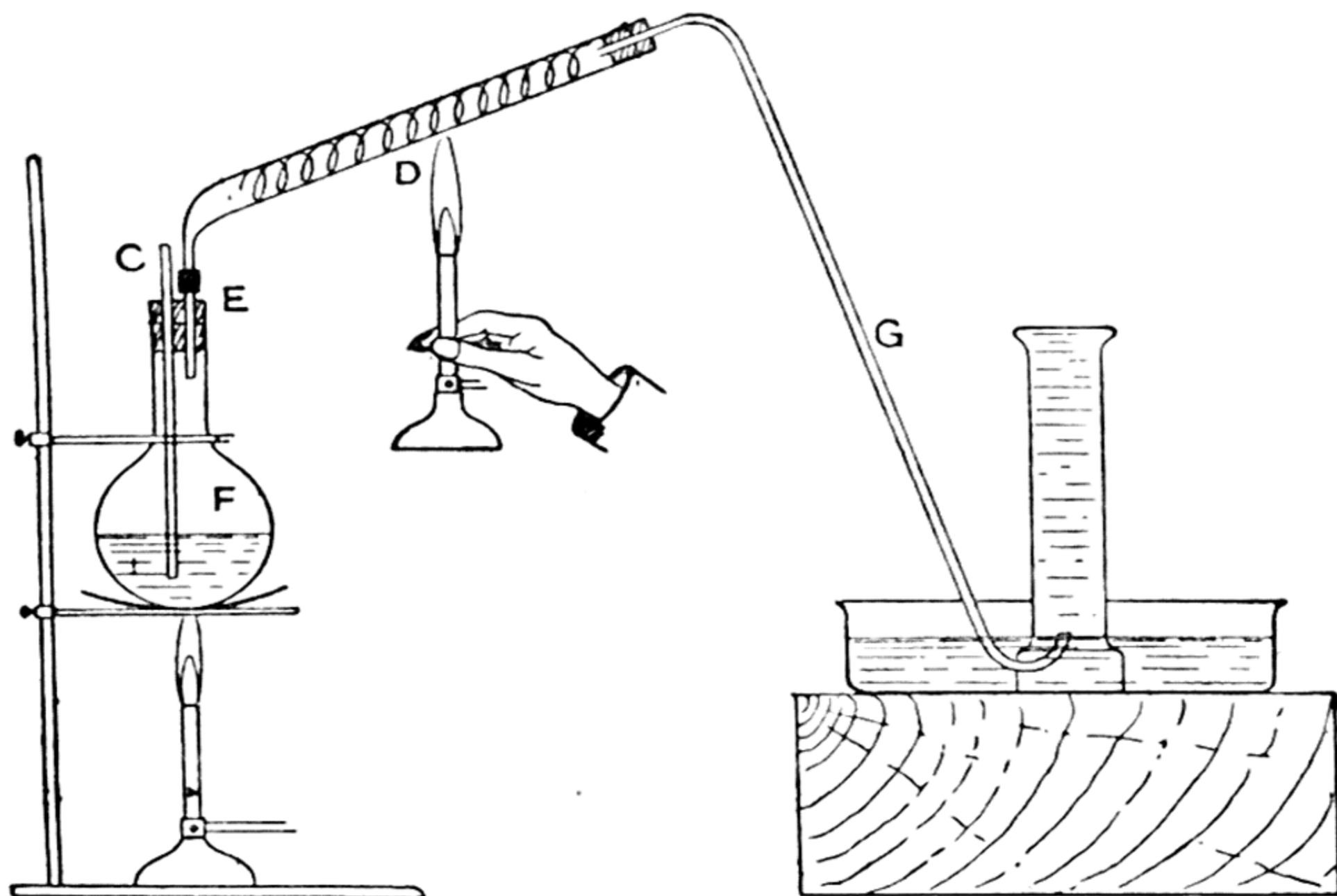


Fig. 161. — Action of Steam on Magnesium

in the form of a spiral in the upper part of a length of hard glass (combustion) tubing, as shown in fig. 161. Bring the water in the flask almost to the boil and then heat the combustion tube gently with a nearly luminous bunsen flame. When the combustion tube is above  $100^{\circ}\text{C}$ . (so that steam will not condense on it and cause it to crack on further heating) boil the water in the flask gently, and when all the air has been expelled from the apparatus, i.e. when no more gas bubbles out through the delivery tube, place a gas jar full of water on the bee-hive shelf. Now heat the combustion tube strongly until the magnesium ignites. When the reaction is over stop the current of steam and allow the combustion tube to cool down.

The white solid in the tube is easily recognized as that obtained by burning magnesium in air, i.e. magnesium oxide. Test the gas in the gas jar with a lighted taper. It burns with an almost colourless flame. It is hydrogen.

In the above experiment water in the form of steam has been split up by the heated magnesium, which has seized the oxygen and liberated the hydrogen. The latter is carried on by the current of unchanged steam and collects in the gas jar. A similar result can be obtained by passing steam through a tube containing heated iron. The iron is converted into a substance which is the same as that obtained when iron burns in oxygen, and hydrogen passes on. A further experiment, which shows us not only that water is composed of oxygen and hydrogen but also the proportions in which these are present, is the **electrolysis** of water — its decomposition by means of an electric current.

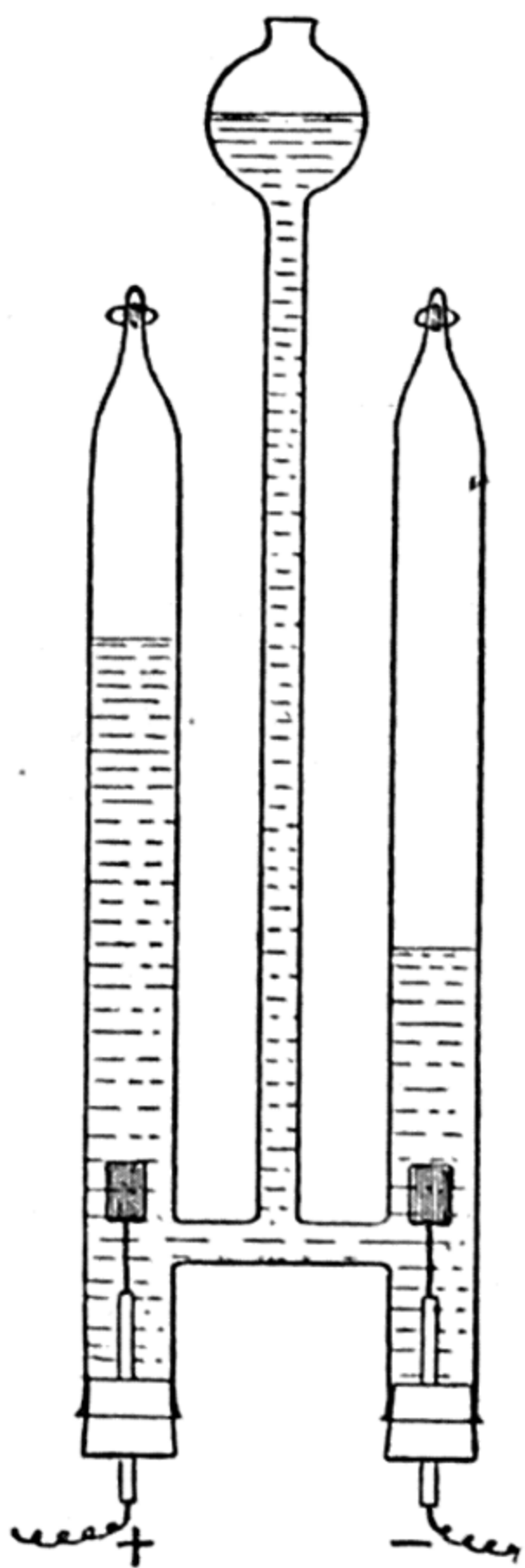


Fig. 162.  
Electrolysis of Water

**EXPERIMENT 78. — The electrolysis of water.** The two gas burettes in the apparatus shown (fig. 162) are filled with water containing a little sulphuric acid by opening the taps and pouring the liquid into the open tube. The taps are then closed. A current of electricity is passed through the liquid from a battery of accumulators. The current enters the liquid through a piece of platinum wire fused through a glass tube and terminating in a piece of platinum foil (the anode), and leaves the solution through a similar piece of foil called the cathode. The anode is the terminal attached to the positive terminal of the battery and the cathode the one attached to the negative terminal.

When the current is switched on bubbles of gas form at both the electrodes. The shape of the apparatus is such that the gas formed at each electrode is collected separately, displacing water from the burette immediately over it into the reservoir tube. Notice that the gas comes off much more rapidly from the cathode than from the anode. After a convenient quantity of gas has been obtained switch off the current. Observe that almost exactly twice as much gas has been given off at the cathode as at the anode. Open the tap of the cathode burette a little and hold a lighted splint to the gas forced out by the greater head of water in the reservoir tube. The issuing gas burns. Open the other tap and hold a glowing splint to the issuing gas. The splint bursts into flame.

In the above experiment it was necessary to add some sulphuric acid to the water, as pure water does not conduct electricity, while a solution of sulphuric acid does. In order to be sure that the gases obtained had not come from the acid we could have put a known amount of acid into the water to start with, obtained a large quantity of gases by electrolysis, and then shown that the amount of sulphuric acid present had not altered. A method of finding the amount of acid present in a solution will be described later.

### The Composition of Water by Weight.

It follows from the experiment that water consists of the two gases, hydrogen and oxygen, in the ratio of two to one by volume. Since, however, oxygen is 16 times as heavy as an equal volume of hydrogen, 18 grams of water contain 16 grams of oxygen and 2 grams of hydrogen, i.e. water is  $\frac{8}{9}$  oxygen *by weight*.

The composition of water by weight can be found by another experiment which, however, requires considerable apparatus and very careful weighing to obtain an accurate result. The principle of the experiment is as follows: some dry powdered copper oxide in a porcelain boat is placed in a combustion tube and strongly heated while a stream of dry hydrogen is

passed over it (fig. 163). The hydrogen reacts with the copper oxide, taking away its oxygen and thereby converting it into metallic copper. The hydrogen combines with this oxygen to form water vapour, which is carried by the stream of incoming hydrogen into a U-tube containing calcium chloride, which absorbs the water vapour. The porcelain boat and drying tube are weighed before and after the experiment. The loss of

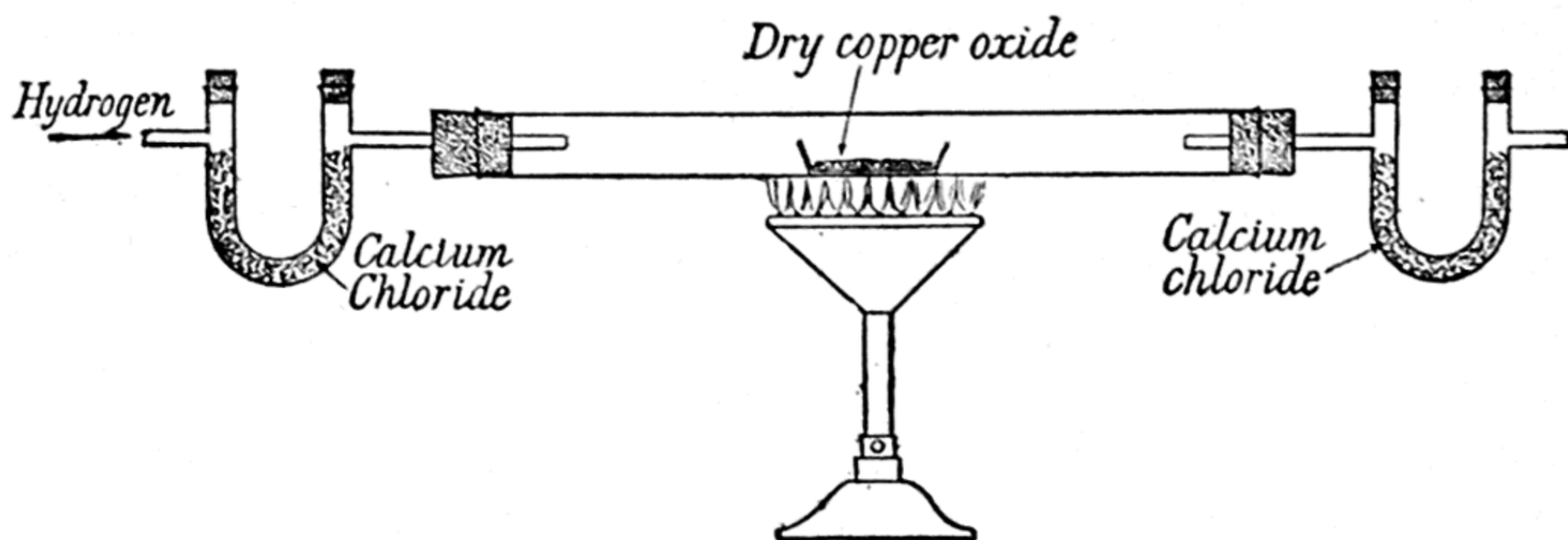


Fig. 163. — The composition of water by weight

weight of the boat and its contents give us the weight of oxygen removed by the hydrogen and the increase in weight of the U-tube is the weight of water produced. By subtraction we can find the weight of hydrogen in the water. Thus:

Loss of weight of boat = 0.16 gm.

Increase in weight of U-tube = 0.18 gm.

therefore

Weight of hydrogen = 0.02 gm.

so that

Proportion of oxygen to hydrogen is  
as 0.16:0.02, i.e. as 8 is to 1.

## Oxidation and Reduction.

In this reaction oxygen has been removed from the copper oxide. This is called **reduction**, and the copper oxide is said to be reduced to copper. On the other hand, oxygen has been added to the hydrogen. This is an **oxidation**. The hydrogen has been oxidized to water.

EXPERIMENT 79. — To show the reduction of copper oxide to metallic copper by hydrogen. Take a test-tube, and with a fine blow-pipe flame soften a small area near the closed end (fig. 164, *a*). Remove the blow-pipe flame, and by

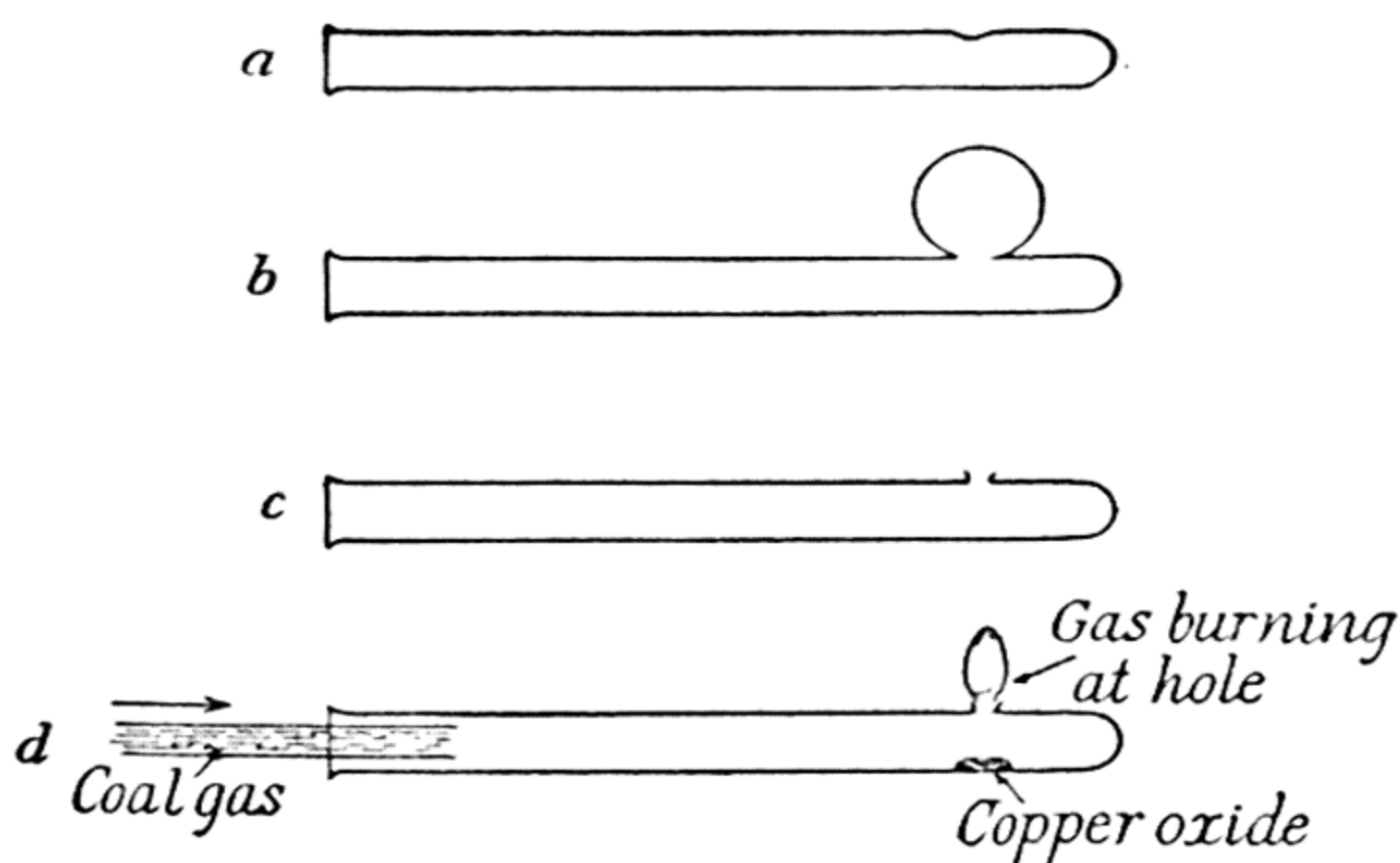


Fig. 164. — Making a Hole in the side of the Test-tube

blowing at the open end of the tube blow a large bulb (*b*), and break off the thin-walled bulb so as to leave a hole in the side of the tube (*c*). Place about 0.5 gm. of copper oxide in the tube and weigh. Attach a piece of bunsen tubing to a gas tap and put the other end of the tubing in the test-tube. Turn on the gas and ignite it at the hole (*d*). Now heat the copper oxide strongly with a bunsen. Coal-gas contains about 40 per cent of hydrogen, to which it owes its lightness, and this soon reduces the oxide to bright red metallic copper. Allow the tube to cool down, and then weigh it again. There is a loss in weight owing to the oxygen having been removed from the oxide.

## The Indestructibility of Matter.

Throughout the two preceding chapters we have made an assumption which we have not stated in words. It is that when a chemical change occurs the total weight of all the products is exactly equal to the total weight of the substances taking part in the change. This assumption is called the **Principle of the Conservation of Matter** or of the **Indestructibility of Matter**. This principle has been tested by innumerable experiments and has been found to hold in all the cases examined. The following is a simple example.

**EXPERIMENT 80.** — To show that there is no change in weight when a chemical reaction occurs. Put 2 c.c. of concentrated copper sulphate solution in a test-tube and stand the test-tube up in a beaker containing 25 c.c. of concentrated caustic soda solution. Weigh the beaker and contents. Lower the beam of the balance, and without removing the beaker from the scale pan pour the contents of the test-tube into the beaker and replace the empty test-tube, taking care that no drops of liquid fall off the tube. A thick heavy-looking blue precipitate forms in the beaker. Raise the beam of the balance. There has been no change in weight.

## QUESTIONS

1. Why is absolutely pure water never found in nature?
2. Summarize the evidence for the belief that water is a compound of hydrogen and oxygen.
3. Describe carefully an experiment which you have seen relating to the electrolysis of water and state what important facts you have learned from it. L.
4. Describe briefly two different methods by which hydrogen can be prepared from water. Name two properties of the gas which make it of commercial importance and use. L.
5. Describe an experiment by which the composition of water *by weight* can be determined. Point out the precautions necessary in carrying out the experiment. L.

## CHAPTER XVI

### SOME SIMPLE CHEMICAL THEORY

#### Chemical Elements.

We have seen in the two preceding chapters that it is possible to separate both air and water into two or more different substances. Thus air is composed of oxygen, nitrogen, argon, etc., and water is composed of oxygen and hydrogen. Scientists are continually experimenting with substances, trying to split them up, to analyse them, to find out what they are made of. Of all the innumerable substances found on the earth very few have defied all our attempts to split them up into different components. These few, about ninety in all, some of them very rare, we call **elements**. These, we believe, are the simple substances from which everything else is made up. At one time earth, air, fire, and water were thought of as elements. Fire, we now know, is not a substance at all (p. 232), while earth, air, and water have all been split up into simpler substances. It is possible that some of these substances we now consider to be elements may yet be found to be composed of two or more simpler substances. In this case we should no longer apply the term element to them. Of the substances we have already met with, copper, iron, magnesium, aluminium, tin, lead, zinc, sodium, oxygen, hydrogen, nitrogen, sulphur, phosphorus, and carbon are all elements. A more complete list is given on page 256.

## Compounds and Mixtures.

If we mix together one volume of oxygen, a colourless odourless gas that supports combustion much better than does air, and four volumes of nitrogen, a colourless odourless gas that does not support combustion at all, we get, as we should expect, a colourless, odourless gas that supports combustion to exactly the same extent as air. Air is a **mixture** of the gases contained in it. When we mix two volumes of hydrogen with one volume of oxygen, we obtain three volumes of a colourless, odourless gas — a mixture of the two gases. Not until we ignite the mixture, when there is a violent chemical reaction — an explosion — do we get any water formed. Water is a liquid, and its properties are very different from those of the gases of which it is composed. In the chemical reaction by which it is formed, the hydrogen and oxygen unite very closely, so that in water the two constituents are held together by a very powerful force that we call **chemical attraction**. Water is what is termed a **compound**.

We can mix two substances together in any proportions we like, and the properties of the mixture are just what we should expect from the proportions we have used. The more soot we mix with snow, the darker the mixture becomes. But in a compound the constituents are always present in definite proportions. Thus, water always contains eight times as much oxygen as hydrogen by weight, and blue copper sulphate crystals always contain 36 per cent of water. This fact is sometimes called the **Law of Fixed Proportions**, or the **Law of Constant Proportion**. Furthermore, as we have seen, the properties of a compound are quite different from those of its constituents.

The difference between a mixture and a compound can readily be illustrated by the case of iron and sulphur.

**EXPERIMENT 81.** — To show the differences between a mixture of iron and sulphur and a compound of the same two substances. Make a mixture of two parts (by weight) flowers of sulphur and three parts clean iron filings. The mixture has a greenish colour, and when a magnet is brought up to it iron filings cling to the magnet and can be shaken free from adherent sulphur particles. Shake up a little of the mixture in a test-tube with 10 c.c. of carbon disulphide (see Caution, Exp. 52, p. 161), filter the liquid on to a watch-glass, and allow it to evaporate in a fume chamber. The iron filings remain on the filter paper and sulphur crystallizes out on the watch-glass.

Fill a test-tube a quarter full of the mixture and heat it in a bunsen flame. After a while the mixture begins to glow. Take the test-tube out of the flame and notice that the red glow due to the chemical reaction between the sulphur and the iron spreads throughout the contents of the tube. When the reaction is over allow the tube to cool and then break it to obtain the product of the reaction. It is a black mass which does not burn when held in a bunsen flame, and which is not attracted by a magnet. Take a piece that has been heated in the flame, powder it up, and endeavour to extract sulphur from it with the aid of carbon bisulphide. Nothing dissolves.

The properties of the compound of iron and sulphur (ferrous sulphide) obtained in the above experiment are quite different from those of a mixture of iron and sulphur. Moreover, while we can mix sulphur and iron in any proportion we like, the compound ferrous sulphide always contains 56 parts by weight of iron to 32 parts of sulphur. If we had taken a larger proportion of sulphur than this in a mixture, the excess sulphur would have burned off when we heated it. If we had taken a smaller proportion of sulphur some of the iron would have been left over, uncombined. Once the mixture had been heated sufficiently to start the reaction, the iron and sulphur gave out sufficient heat to make the mass red-hot. Heat is given out when very many chemical reactions occur — the burning of substances in air is an obvious example and the solution of zinc in dilute acid in the preparation of hydrogen is another. Heat is a form of energy, so that all these

reactions result in energy being given out. This energy is most frequently liberated in the form of heat, but sometimes also as light, sound, or mechanical energy, as in the case of explosions. Not all chemical reactions result in energy being given out, however; in some cases we have to put in energy in order to keep the reaction going. An example of this is the electrolysis of water, where energy is supplied in the form of electricity. As soon as the current of electricity is switched off the decomposition of the water stops also. This will not surprise us, for when oxygen and hydrogen combine much energy is given out. Hydrogen burns in air with a very hot flame. We should naturally expect, therefore, to have to put this energy back in order to decompose water. If we could do it without putting any energy back, by burning the oxygen and hydrogen thus obtained, again decomposing the water formed, and so on, we could get an unlimited supply of energy for nothing, but as we saw on p. 199, this cannot be done. The energy we have to put in in order to decompose water is stored up in the oxygen and hydrogen as **chemical energy**, and we can recover it in the form of heat when these two substances combine.

When the sulphur and iron filings are merely mixed together, it is quite easy to separate the constituents. The iron can be extracted by means of a magnet, or the sulphur may be dissolved out by carbon disulphide. A mixture of salt and sand can be separated by dissolving out the salt with water and then filtering off the sand. The sand remains on the filter paper and the salt can be recovered by evaporating the clear filtrate. The components of air can be separated by liquefying the air and then allowing the lowest-boiling component to evaporate off first (p. 232). These methods are called **physical methods**, because they do not involve the formation of any new chemical compound or the decomposition of any of the original compounds.

The solution of salt in water is a **physical change**, because both the water and the salt are present in the solution and can be recovered from it unchanged. The conversion of water into ice or steam is also a physical change, for although the new substances have different properties from the original one, they have the same chemical composition. Steam, like water and ice, is a compound of hydrogen and oxygen in the proportion of eight parts by weight of oxygen to one part by weight of hydrogen. But the solution of zinc in dilute sulphuric acid is a **chemical change**, because the zinc has ceased to exist as uncombined zinc and has been converted into a solid crystalline substance called zinc sulphate that can be obtained by crystallization from the liquid in the flask (Experiment 74). The components of mixtures can be separated by physical methods, that is to say, methods not involving the formation of substances with a different chemical composition, but **chemical methods** must be employed to separate the component parts of a compound.

We may summarize the differences between mixtures and compounds thus:

#### MIXTURES.

1. Components may be present in any proportion.

2. A mixture has properties intermediate between those of its components.

3. The components of a mixture can be separated by physical methods.

#### COMPOUNDS.

Components are always present in the same fixed proportions, the actual ratio depending on the compound considered.

The properties of a compound are quite different from those of its components.

The components of a compound can be separated only by chemical methods.

## MIXTURES.

4. The formation of a mixture is not always accompanied by evolution or absorption of heat.

## COMPOUNDS.

The formation of a compound is always accompanied by the evolution or absorption of heat, light, or other form of energy.

**Atoms.**

The word **atom** is really a Greek word and means "indivisible". As long ago as the 5th century B.C., Leucippus and Democritus, celebrated Greek philosophers, taught that everything material was composed of enormous numbers of very tiny particles, too small to be seen or counted, and absolutely indestructible. A piece of matter could be divided into smaller and smaller pieces, they said, but when these pieces became so small as to consist of single atoms, no further subdivision was possible. The atoms were "indivisibles".

Although these old Greek ideas were never entirely forgotten, and were revived from time to time, it was not until the time of Dalton (1766–1844) that the **Atomic Theory**, as we call it, took the form in which we know it to-day. There was a reason for this. About that time chemists had made many remarkable discoveries, and Dalton saw that these discoveries could be used as evidence in support of his ideas. Dalton's theory was not guesswork, but was based on experiments.

**Dalton's Atomic Theory.**

Dalton made the following assumptions:—

1. Matter is composed of exceedingly small particles called atoms, which cannot be split up or subdivided, and which cannot be created or destroyed in any way whatever.

2. Atoms of the same element are all exactly alike and have the same weight.
3. Atoms of different elements have different properties and different weights.
4. Compounds are formed by the union of small numbers of atoms of different kinds, e.g. one atom of one element with one atom of another, one atom of one element with two of another, and so on.

With the aid of these assumptions it is possible to give an explanation of two important facts that we have already discovered. When hydrogen burns in air to form water the atoms of hydrogen unite with the atoms of oxygen; when steam is passed over heated magnesium the oxygen atoms that were originally combined with hydrogen atoms forsake the latter and combine with magnesium atoms, leaving uncombined hydrogen atoms. In these and all other reactions, the atoms concerned combine, or exchange partners, but, since atoms cannot be created or destroyed, the total number of each kind present after the reactions must be exactly the same as at the beginning. And since atoms of the same kind always have the same weight, the total weight of the products must be the same as that of the original substances. In other words, if the Atomic Theory is true, then the Principle of the Indestructibility of Matter (p. 246) must be true also. Of course, it does not follow that because this Principle has been found by experiment to be true that the Atomic Theory is necessarily true also. If a substance is pure gold, then it must be yellow. If the substance is yellow it may be pure gold, but it need not necessarily be pure gold.

## Molecules.

It is clear that the smallest particles of a compound must consist of at least two atoms. Although at one time the term atom was used for such compound particles, we now call them **molecules**. The reason for making this distinction is that molecules can be split up while atoms cannot. But when we split up a molecule of a compound we get something different from that compound. Thus, when hydrogen is passed over copper oxide, the molecules of the latter are split up, but as a result the copper oxide ceases to exist as copper oxide and is converted into something else, the copper atoms being liberated and the oxygen atoms combining with the hydrogen atoms to form molecules of water. A molecule, then, is the smallest particle of a compound that can exist.

We use the term molecule in connection with elements as well as in connection with compounds, for it has been found that in such gases as oxygen, hydrogen, and nitrogen the atoms always form pairs, so that each of the smallest particles of these gases consists of two atoms combined together. In the same way, atoms of sulphur group themselves in molecules each consisting of eight atoms, and atoms of phosphorus into molecules consisting of four atoms. When these molecules take part in a chemical reaction they split up, and enable the individual atoms to combine with atoms of other elements. We may define **a molecule of an element as the smallest particle of the element that can exist under ordinary conditions**, and an atom as **the smallest particle of an element that can take part in a chemical change**.

## The Size and Weight of Atoms.

It is only comparatively recently that we have been able to discover the size and weight of atoms, although

[illegible]

### Atomic and Molecular Weights.

Although chemists frequently speak of the **atomic weights** of the atoms of different elements, they do not measure them in grams, for, as we have seen, the weights of atoms are far too small for this to be convenient. A new unit of weight is taken, and this is the weight of an atom of hydrogen. Since hydrogen is the lightest atom, all other atomic weights must be greater than 1. When we say that the atomic weight of oxygen is 16, we mean that an atom of oxygen weighs as much as 16 atoms of hydrogen. The same unit is used in measuring **molecular weights**. The molecular weight

of water is 18, that is, one molecule of water, the smallest particle of water that can exist, weighs 18 times as much as a hydrogen atom.

### Symbols and Formulæ.

It is usual in chemistry to use certain abbreviations or symbols to represent atoms of particular elements. In many cases the symbols used are the first letters of the ordinary name of the element. Thus O represents one atom of oxygen, H one atom of hydrogen, N one atom of nitrogen, and so on. Since, however, there are about ninety elements and only twenty-six letters in the alphabet, it necessarily happens that several elements have the same initial letter. In such cases two letters are used, the first a capital and the second a small letter, e.g. C carbon, Ca calcium, Cl chlorine. In the case of many of the metals the initials used are those of their Latin names, e.g. Au (*aurum*) gold, Ag (*argentum*) silver, Pb (*plumbum*) lead.

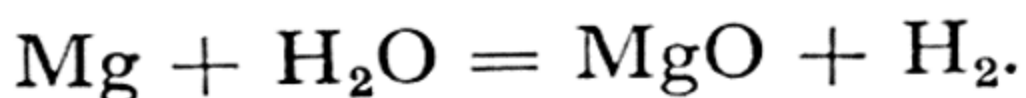
#### LIST OF SYMBOLS AND ATOMIC WEIGHTS.

Aluminium	..	Al	27	Mercury			
Argon	..	A	40	( <i>hydrargyrum</i> )	Hg	201	
Boron	..	B	10.9	Neon	..	Ne	20
Bromine	..	Br	80	Nickel	..	Ni	58.7
Calcium	..	Ca	40	Nitrogen	..	N	14
Carbon	..	C	12	Oxygen	..	O	16
Chlorine	..	Cl	35.5	Phosphorus	..	P	31
Chromium	..	Cr	52	Platinum	..	Pt	195
Cobalt	..	Co	59	Potassium			
Copper ( <i>cuprum</i> )		Cu	63.5	( <i>kalium</i> )	..	K	39
Gold ( <i>aurum</i> )	..	Au	197	Silicon	..	Si	28
Helium	..	He	4	Silver			
Hydrogen	..	H	1	( <i>argentum</i> )	Ag	108	
Iodine	..	I	127	Sodium			
Iron ( <i>ferrum</i> )		Fe	56	( <i>natrium</i> )	..	Na	23
Lead ( <i>plumbum</i> )		Pb	207	Sulphur	..	S	32
Magnesium	..	Mg	24	Tin ( <i>stannum</i> )		Sn	119
Manganese	..	Mn	55	Zinc	..	Zn	65

When two or more atoms combine together to form a molecule of a compound, the composition of the latter can be shown by writing down, one after the other, the symbols of the atoms present. Thus,  $\text{MgO}$  represents one molecule of magnesium oxide, consisting of one atom of magnesium combined with one atom of oxygen. This abbreviated or shorthand form of writing the composition of a molecule of a compound is called the **formula** (plural **formulae**) of the compound. When a molecule contains more than one atom of a particular element, the number of atoms present is indicated by a small number written below the line after the symbol of the element. Thus,  $\text{H}_2\text{O}$  represents a molecule of water, consisting of two hydrogen atoms and one oxygen atom,  $\text{CO}_2$  represents a molecule of carbon dioxide, consisting of one atom of carbon and two atoms of oxygen. In the same way, the molecules of gaseous oxygen, hydrogen, and nitrogen are written as  $\text{O}_2$ ,  $\text{H}_2$ ,  $\text{N}_2$  respectively, since each of these consists of two atoms.

### Chemical Equations.

With the aid of formulae we can show in a very helpful way what is happening in a chemical reaction. The reaction that occurs when steam is passed over heated magnesium can be written:



This is called a **chemical equation**, and tells us that one atom of magnesium reacts with one molecule of steam (which has the same chemical composition as water) to give one molecule of magnesium oxide and one molecule of hydrogen.

To indicate two or more atoms or molecules, we put the appropriate number in front of the symbol or formula: thus  $2\text{H}_2\text{O}$  represents two molecules of water, consisting altogether of four atoms of hydrogen

and two of oxygen. The big 2 in front applies to everything after it, while the small 2 after the H applies only to the symbol immediately in front of it.

Sometimes two compounds unite together without any other substance being split off. For example, anhydrous copper sulphate unites with water to give blue hydrated crystals. The union of compounds is indicated by writing the formula for each of the molecules taking part, and putting a dot on the line, between the formulæ. The formula for anhydrous copper sulphate is  $\text{CuSO}_4$ , that of the hydrated crystals is  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ . This tells us that in the blue crystals each molecule of copper sulphate is combined with five molecules of water.

Since in a chemical reaction atoms are neither created nor destroyed, it follows that in every equation the number of atoms of each element must be the same on both sides of the equation. In the example given above, there are two atoms of hydrogen on the left-hand side, and therefore there must be two atoms of hydrogen on the right-hand side also; one atom of magnesium on the left-hand side, and therefore one atom of magnesium on the right-hand side. This fact gives us a simple method of checking an equation if we are not quite sure whether we have written it down correctly.

Given below are the equations referring to some of the reactions we have already considered. Find out the experiment to which each refers, and re-write the equation in words similar to the example given above of the action of steam on magnesium.

1.  $\text{Fe} + \text{S} = \text{FeS}$ .
2.  $2\text{Mg} + \text{O}_2 = 2\text{MgO}$ .
3.  $2\text{H}_2 + \text{O}_2 = 2\text{H}_2\text{O}$ .
4.  $\text{CuO} + \text{H}_2 = \text{Cu} + \text{H}_2\text{O}$ .
5.  $\text{C} + \text{O}_2 = \text{CO}_2$ .
6.  $\text{CuSO}_4 + 5\text{H}_2\text{O} = \text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ .

## The Atomic Theory and the Law of Fixed Proportions.

Each chemical compound always has the same proportion of each of its constituents. This has been tested over and over again by preparing a compound in every possible way, and then finding out by analysis how much it contains of each element that is present in it. The Law of Fixed Proportions is one of the pieces of experimental evidence in favour of the Atomic Theory, for the theory gives us a very simple explanation of this constancy of composition. If water consists of molecules each containing two atoms of hydrogen and one of oxygen, then, since all hydrogen atoms have the same weight (Assumption 2, p. 253) and all oxygen atoms weigh 16 times as much as a hydrogen atom, the proportion of each present in water must always be as 2 : 16, i.e. as 1 : 8, by weight. This has been found to be true by analysis of various samples of pure water.

### QUESTIONS

1. Distinguish between an element, a mixture, and a compound. Illustrate your answer by reference to air and water, giving numerical details if possible. L. (part)

2. Explain the difference between physical solution and chemical solution, and give one example of each.

3. In what ways would you expect a mixture of two substances to differ from a compound of the same two substances?

4. What do you understand by the terms *atom*, *molecule*, *atomic weight*, *molecular weight*? What is the molecular weight of (i) water ( $\text{H}_2\text{O}$ ), (ii) magnesium oxide ( $\text{MgO}$ ), (iii) sulphuric acid ( $\text{H}_2\text{SO}_4$ )? (Refer to the table of atomic weights on p. 256).

5. How does the Atomic Theory give us an explanation of (i) the Principle of Conservation of Matter, and (ii) the Law of Fixed Proportions?

6. The atomic weight of hydrogen is 1 and of oxygen 16. What do you understand by this statement?

## CHAPTER XVII

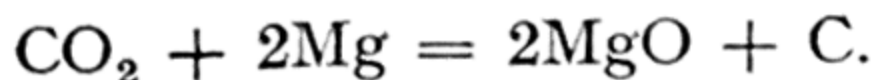
### CARBON DIOXIDE. RESPIRATION

Carbon dioxide is formed directly from the elements composing it when carbon burns in air or oxygen (p. 227), but it is most conveniently prepared by the action of dilute hydrochloric acid on marble chippings.

**EXPERIMENT 82. — To prepare Carbon Dioxide and examine its properties.** Put some marble chippings in a Woolf's flask fitted with a thistle funnel and delivery tube, as shown (fig. 165). On adding dilute hydrochloric acid down the funnel, a brisk effervescence takes place. As the gas is rather soluble in water it is collected by displacement of air, the heavy carbon dioxide being led into the bottom of the gas cylinder, displacing the air upwards.

The gas is colourless and odourless. Hold a lighted taper to the mouth of the cylinder. When the cylinder is full of the gas the taper is extinguished. Collect several jars of gas.

Plunge a lighted taper into a jar of the gas. The taper is immediately extinguished. Other burning substances, with the exception of magnesium, are extinguished in the same way. Take a piece of magnesium ribbon, hold it in a pair of crucible tongs, and ignite it at one end. Quickly plunge the burning ribbon into a cylinder of carbon dioxide. The magnesium burns brilliantly, and the surface of the cylinder becomes coated with a white powder, with which are mixed numerous black specks. The carbon dioxide has been decomposed by the burning magnesium, which has combined with the oxygen to form magnesium oxide, and the carbon has been set free:



It is clear from the method used in preparing the gas that it is heavier than air. This can also be shown by counterpoising a large beaker on a balance and then pouring the gas

into the beaker from a gas cylinder (fig. 166). The increase in weight of the beaker is immediately apparent.

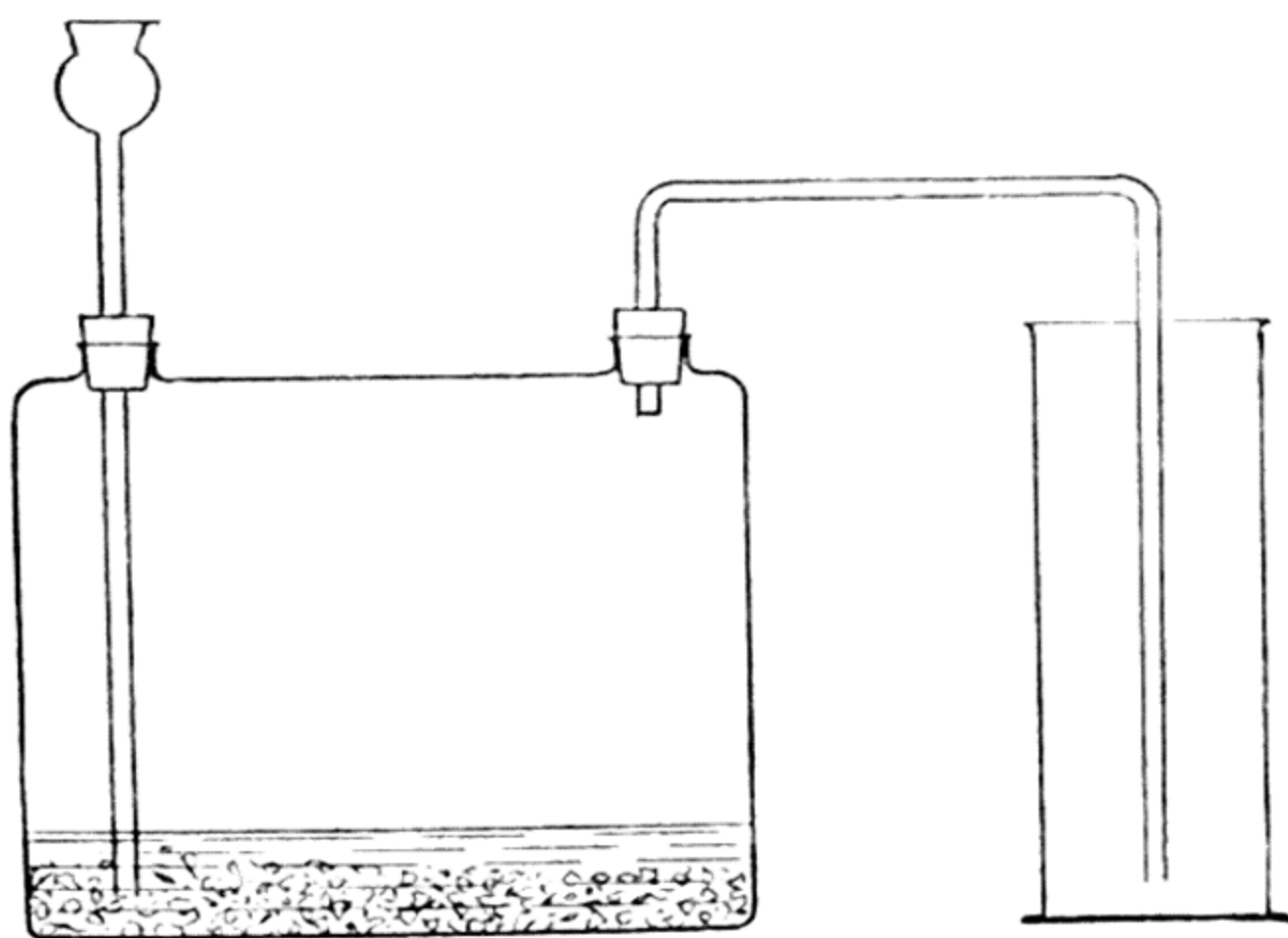


Fig. 165. — Preparation of Carbon dioxide

Fill a test-tube with the carbon dioxide by displacement of air, place a thumb over the top, and invert the test-tube with its mouth under water. The water slowly rises in the tube,

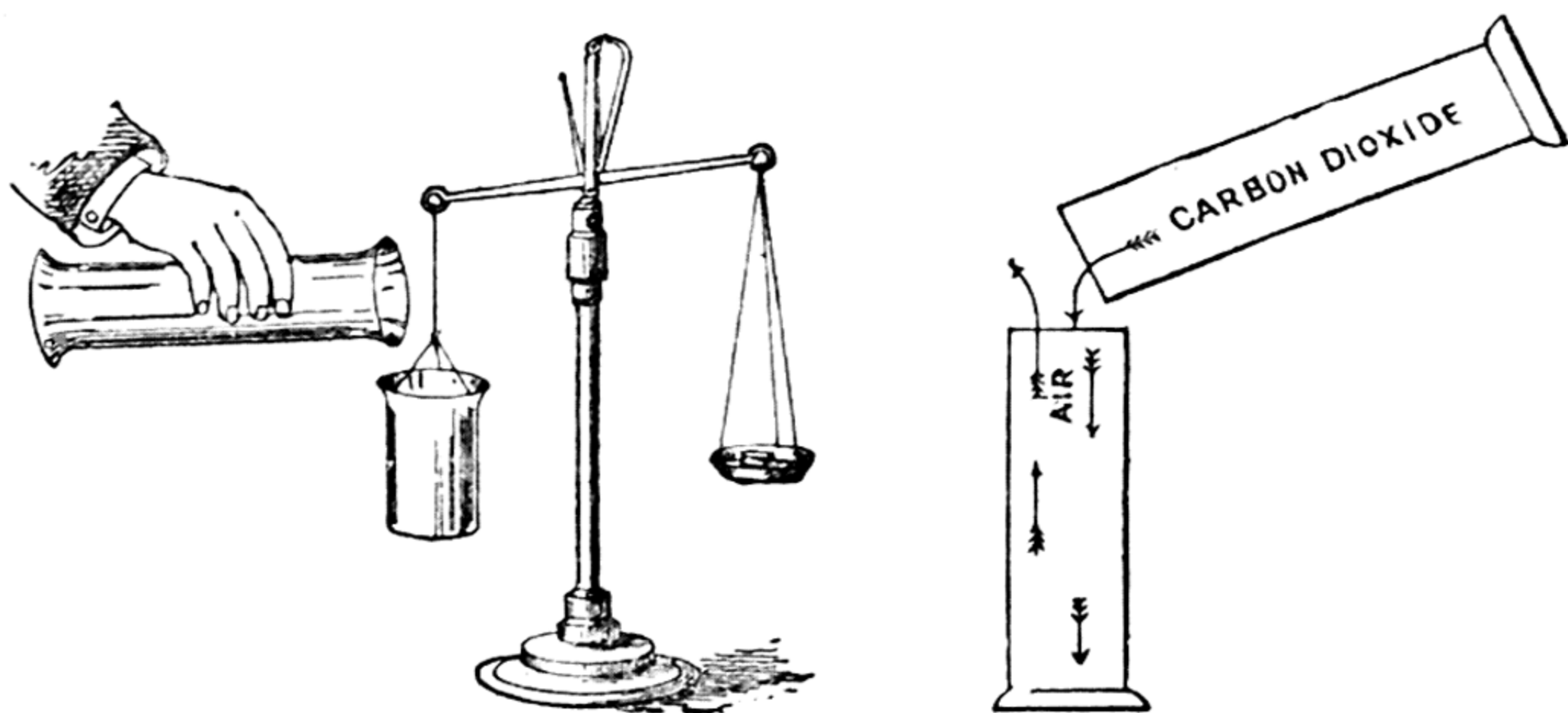


Fig. 166. — Carbon dioxide heavier than Air

showing that the gas is dissolving. Repeat the experiment, but this time invert the test-tube under a solution of caustic soda. The liquid rises much more rapidly in the tube. In the case of water, the solution is purely physical, and on warming

the water that has dissolved the carbon dioxide the gas is given off again, but in the latter case the solution is chemical, i.e. a new compound has been formed. This can be shown by bubbling carbon dioxide for some time into caustic soda solution in a boiling-tube, and then evaporating the liquid to dryness. No bubbles of gas are given off when the liquid is heated, and after evaporation a white solid is left. Add a little dilute hydrochloric acid to this solid. Carbon dioxide is given off. Add a little hydrochloric acid to caustic soda solution. No gas is liberated. The carbon dioxide has combined with the caustic soda to form the white solid, which is called sodium carbonate.

Bubble carbon dioxide through a solution of litmus in a test-tube. The litmus turns red, not the bright red that we get when we add a drop of hydrochloric acid to it, but a port-wine colour. Carbon dioxide is acidic, but not strongly acidic. When dissolved in water it forms carbonic acid.

Bubble carbon dioxide into a test-tube containing some lime-water. The lime-water immediately turns milky owing to the formation of small white particles of a solid that falls to the bottom on standing. This solid is chalk, and the reaction is used as a test for carbon dioxide. Put a small piece of marble in a test-tube and add a little dilute hydrochloric acid. Dip a glass rod in lime-water and hold it in a sloping position so that a drop of the clear liquid hangs from the end of the rod. Hold this just inside the top of the test-tube, being careful not to touch the side of the tube. The drop turns milky.

## **The Combustion of Organic Matter.**

Carbon dioxide is formed whenever organic matter, i.e. animal and vegetable matter, is burned. Most organic matter also contains hydrogen, which is converted into water at the same time. Much heat is given out when organic matter burns.

**EXPERIMENT 83. — To show that Carbon Dioxide and Water are formed when (a) Alcohol, (b) Starch is burned in air.**

(a) Light a spirit lamp containing alcohol and place a bell-jar over the spirit lamp and a small beaker containing lime-water (fig. 167). Note the drops of colourless liquid that condense on the side of the tube, and also that the surface of the lime-water becomes milky. Collect some of the moisture from

the sides of the bell-jar on a piece of filter paper, and then drop on the paper a little powdered anhydrous copper sulphate. The latter turns blue.

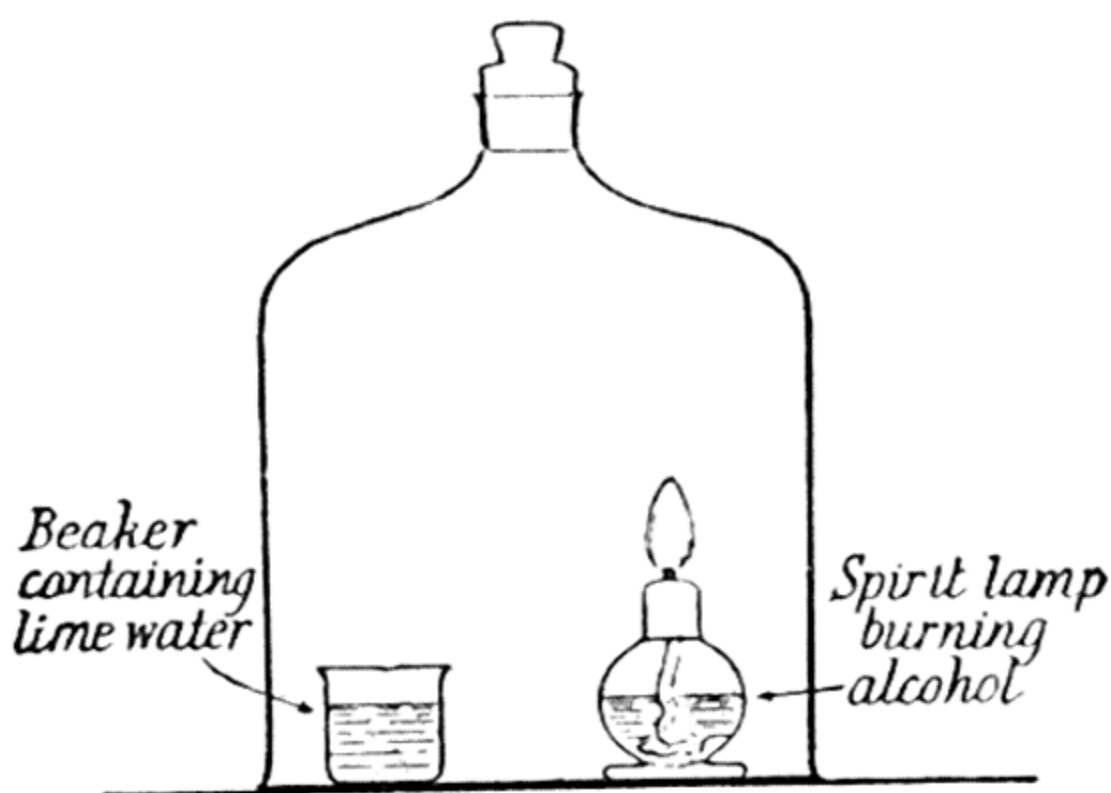


Fig. 167. — Carbon dioxide and water are formed when alcohol burns

(b) Set up the apparatus of fig. 168. A slow current of air can be drawn through it by means of a filter pump, the rate being adjusted so that a steady stream of bubbles passes through the lime-water in the flask. Place a gram or two of starch

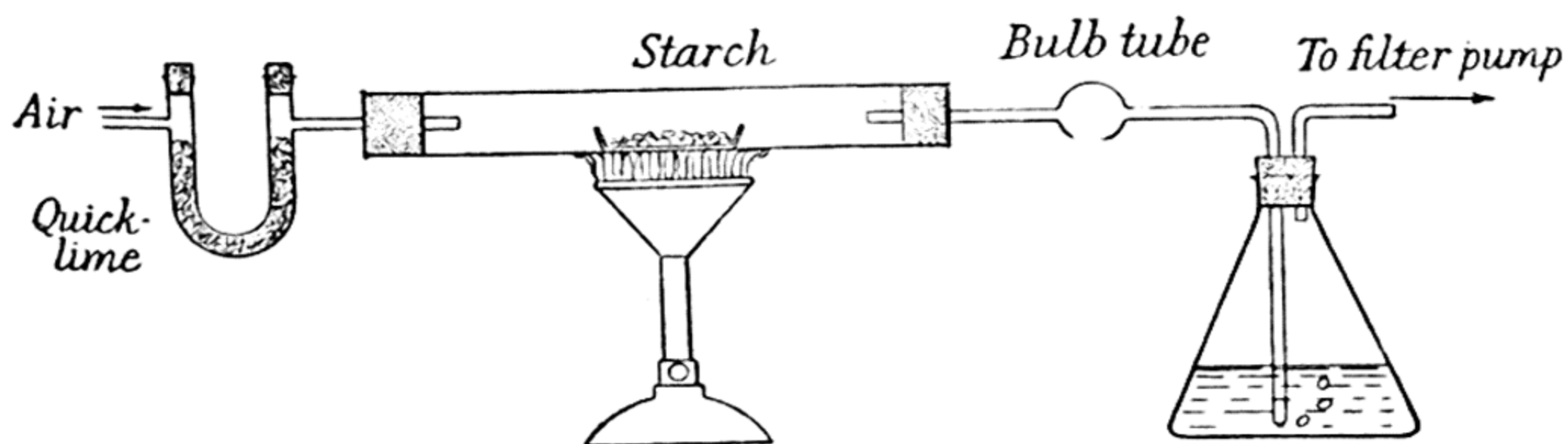


Fig. 168. — Carbon dioxide and water are formed when starch burns in air

in a porcelain boat, and put the latter in a hard glass combustion tube. Pass a current of air through the apparatus for a minute or two and note that the lime-water is unchanged. Heat the combustion tube with a bunsen. The starch slowly burns. Tiny drops of a colourless liquid condense in the cool bulb tube and the lime-water turns milky.

## The Products of Respiration.

We have all noticed that when we breathe on a cold surface, such as a window-pane or a mirror, the latter becomes misty owing to the condensation on it of minute drops of a liquid. If we continue to breathe on the surface for some time quite large drops form. The liquid is water. Evidently the air that we breathe out contains considerably more water vapour than the air we inhale. It has been found also that expired air

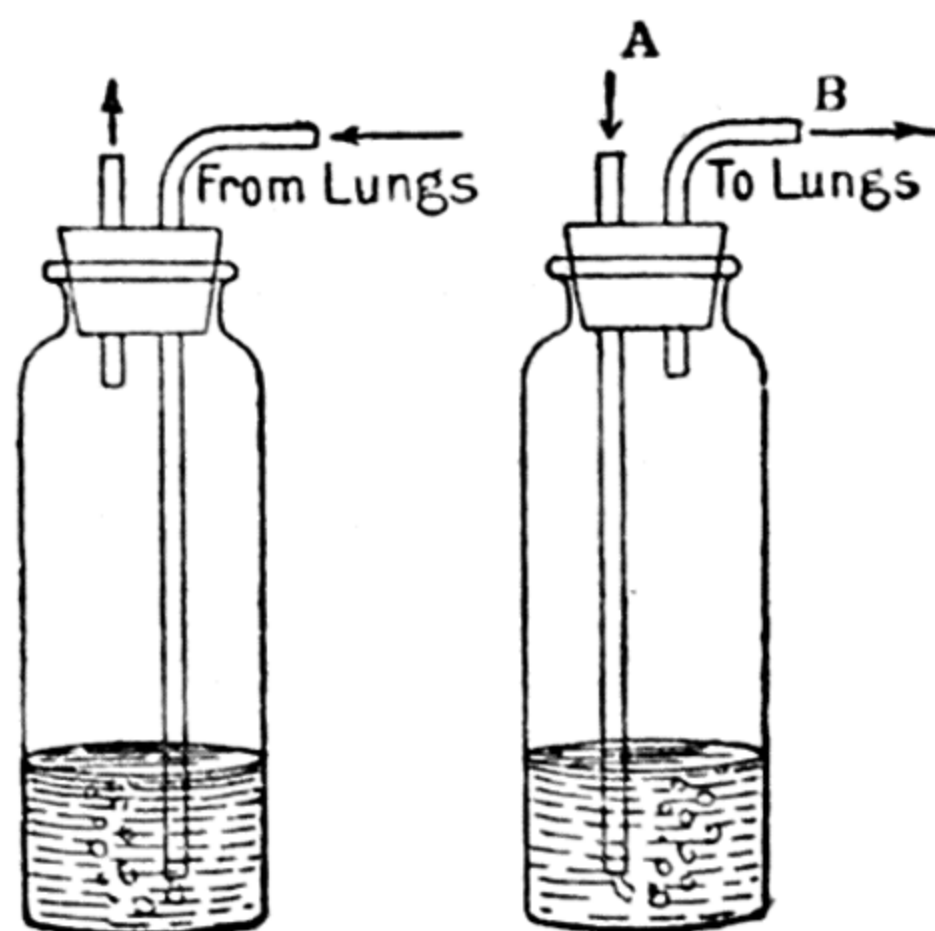


Fig. 169

contains a much larger proportion of carbon dioxide than the air we breathe in. While the latter contains only 0.03 per cent of carbon dioxide, expired air contains nearly 4 per cent. Furthermore, chemical analysis shows that expired air contains only about 16 per cent of oxygen instead of the 21 per cent found in atmospheric air. It follows that during the process of breathing or respiration about one quarter of the oxygen taken in is used up, and carbon dioxide and water vapour are returned to the air in its place.

**EXPERIMENT 84. — To show that expired air contains more Carbon Dioxide than atmospheric air.** Fit up two flasks containing lime-water, as shown in fig. 169. Breathe in

air through the short tube B. Atmospheric air bubbles in through the lime-water to take the place of the air withdrawn. Breathe out through the long tube of the other flask. The expired air bubbles through the lime-water, which becomes much more milky than that in the first flask.

### Respiration Liberates Energy.

When we run up a long flight of stairs, or take violent exercise, we find ourselves breathing deeper and more rapidly — we get “out of breath”, as we say. Although we are actually respiring at a more rapid rate than usual the body demands still more air. Not only does violent exercise cause us to breathe more rapidly, it also makes us hot. It is because of this that when we feel cold we instinctively move about more quickly and try to warm ourselves by taking exercise. In respiration, oxygen is taken in and carbon dioxide and water are given out, and at the same time heat is liberated. We have seen that this is just what happens when organic substances burn in air. In fact, a kind of burning is actually taking place inside the body. Sugar and starch, and other substances taken into the body as food, are burned up, or oxidized, to carbon dioxide and water. Most of the energy that is set free during this process appears as heat, but some of it provides the mechanical energy necessary to enable us to move about, and to do physical work, while yet another part is used to build up from simpler substances the innumerable other chemical compounds that the body needs. This burning up of foodstuffs inside us is not the violent reaction that we see in the laboratory when we burn the same substances in air. It is a much slower and gentler process of “slow combustion”, such as we saw in the case of the piece of phosphorus in Experiment 72 (p. 228).

## The Respiration of Plants.

Plants respire, as well as animals, but since a plant uses up energy at a much slower rate than the more active animal, its respiration occurs at a correspondingly slower rate; hence it is not so easy to demonstrate. As we might expect, plants respire most actively when they are growing most rapidly, and this is when they are germinating. We have already seen (p. 130) that seeds cannot germinate in the absence of air, and by a modification of this experiment it can be shown that it is the oxygen of the air that is used up. At the same time sufficient heat is given out to raise the temperature of the seeds several degrees, if the heat is prevented from escaping by keeping the seeds in a vacuum flask. The following experiments demonstrate that plants give off carbon dioxide.

### EXPERIMENT 85.

(a) Soak a number of peas in water for a few days, and then suspend them in a wet muslin bag in a stoppered bottle with a little lime-water at the bottom. Leave till next lesson. Observe that the lime-water has become milky.

(b) Suspend similarly a number of fresh leaves (e.g. of privet). Leave the bottle in a dark cupboard until the next lesson. Again, the lime-water becomes milky. (The reason for keeping the leaves in the dark will be explained later.)

(c) Support an apple on a large upturned cork at the bottom of a gas cylinder, and pour in lime-water until its level is nearly up to the top of the cork. Put a cover on the gas cylinder and leave it until the next lesson. The lime-water will become milky.

The formation of carbon dioxide by rapidly developing yeast cells has already been shown (p. 173). This is another example of respiration, although in this case the sugar which is the substance being oxidized or burned up is not entirely converted into carbon dioxide and water. Alcohol, the other product of the

fermentation, can itself be oxidized further to carbon dioxide and water. In this case, therefore, only a part of the energy contained in the sugar is liberated.

## QUESTIONS

1. Make a summary of the properties of carbon dioxide. How would you test a jar of gas to show that it contained carbon dioxide?

2. Make a list of the resemblances between carbon dioxide and (a) oxygen, (b) nitrogen.

3. Why does vigorous exercise make one hot and out of breath?

4. What do you understand by the term *respiration*?

5. What is *slow combustion*? Give two examples.

6. What changes in the composition of the air are brought about (a) by green plants, (b) by animals? At what stage of its life does a flowering plant behave in this respect like an animal?  
L.

7. Why do plants respire? How would you show by experiment the respiration of opening buds?

## CHAPTER XVIII

# RESPIRATION AND THE CIRCULATION OF THE BLOOD

We shall now consider in rather more detail the process of breathing. We can breathe in through either the mouth or the nose. The natural way is the nose, for the nostrils warm the incoming air and also filter off dust and germs, which are trapped in a moist secretion called **mucus**. Air entering the nose passes to the back of the mouth and there enters the **trachea**, or windpipe, through a chamber called the **larynx**, which contains the **vocal chords**. The upper surface of this chamber, or voice-box as it is sometimes called, has an opening called the **glottis**, which can be closed by a little flap called the **epiglottis**. This happens when we swallow, and prevents the food or liquid from "going the wrong way", down the windpipe instead of down another tube called the **gullet**, which leads to the stomach. The trachea is stiffened by incomplete rings of cartilage, and at its lower end divides into two tubes called **bronchi** (sing. **bronchus**). These lead to two large organs called the **lungs**, where they branch repeatedly to form smaller and smaller tubes or **broncheoli**, which end in enlarged **air-sacs** (fig. 171, *b*) about  $\frac{1}{40}$  in. in diameter. All round these air spaces are smaller cavities called **alveoli**, the walls of which contain fine blood-vessels or **capillaries**, which bring the blood very close to the surface of the lung. The trachea, bronchi, and their larger branches are lined by ciliated

cells (see fig. 121, *d*) beneath which are other cells that secrete mucus. The tiny **cilia**, by their constant movements, drive mucus upwards to the throat and mouth, carrying with it dust and germs not previously trapped in the nostrils.

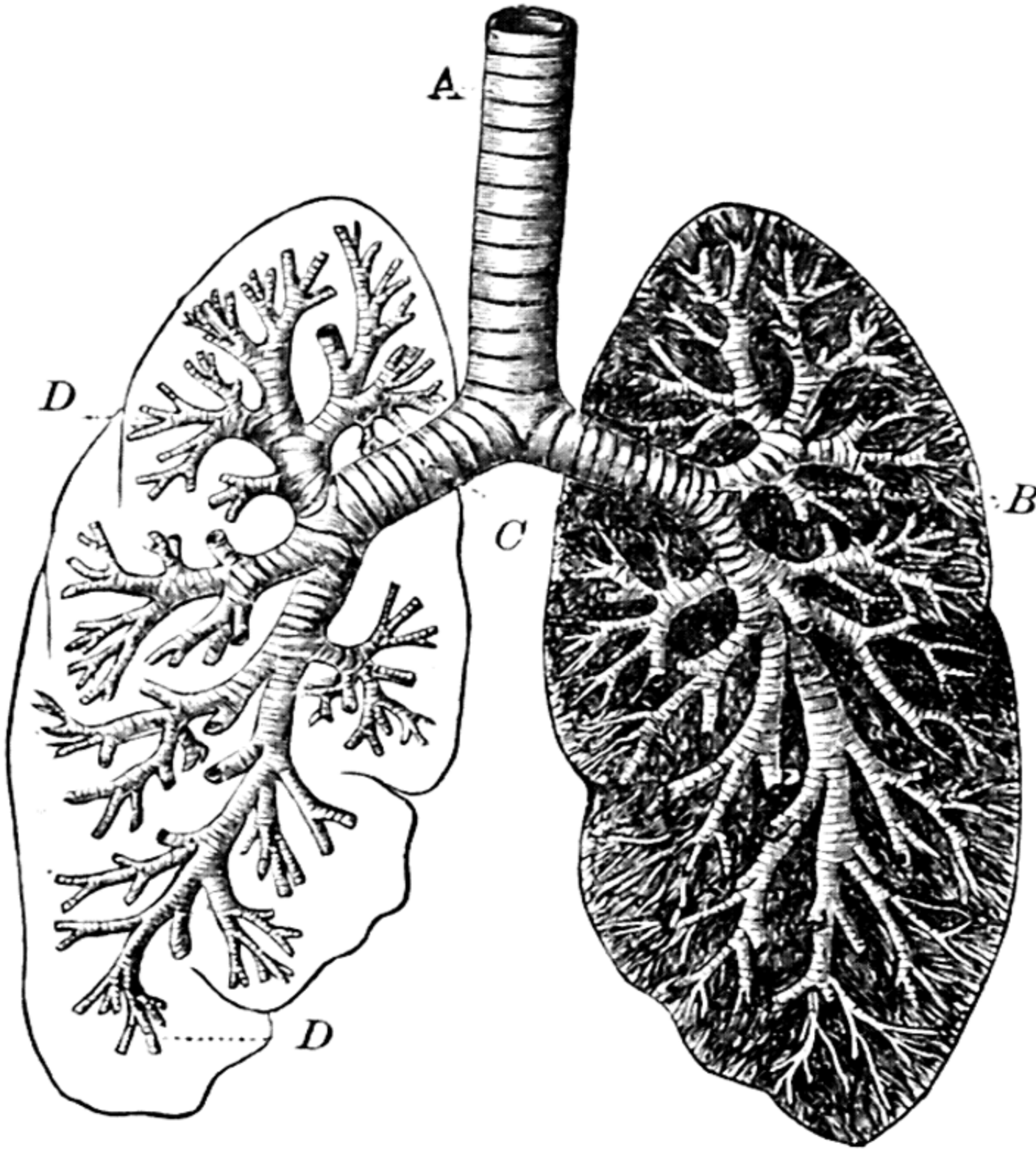


Fig. 170. — Air-tubes of Lungs  
 A, Trachea. B, Left bronchus. C, Right bronchus.  
 D, Bronchial tubes (bronchioli)

The two lungs and the heart practically fill the upper part of the body, an absolutely air-tight cavity called the **thorax**. The thorax is bounded at the top and sides by the wall of the chest, and beneath by a strong dome-shaped muscular partition called the **diaphragm**. The inner surface of the chest wall and the outer surface of the lungs are covered with thin membranes called **pleuræ**, which are moistened by a liquid that acts as

a lubricant and allows the walls of the lungs to move over the chest wall without friction.

If we increase the volume of the thorax in any way, the pressure of the atmosphere outside the body will force air into the lungs, which are elastic and expand to fill the larger volume available. By means of muscles we can increase the volume of the thorax in two ways. Certain muscles attached to the **ribs** can cause the latter to move upwards and forwards, carrying the

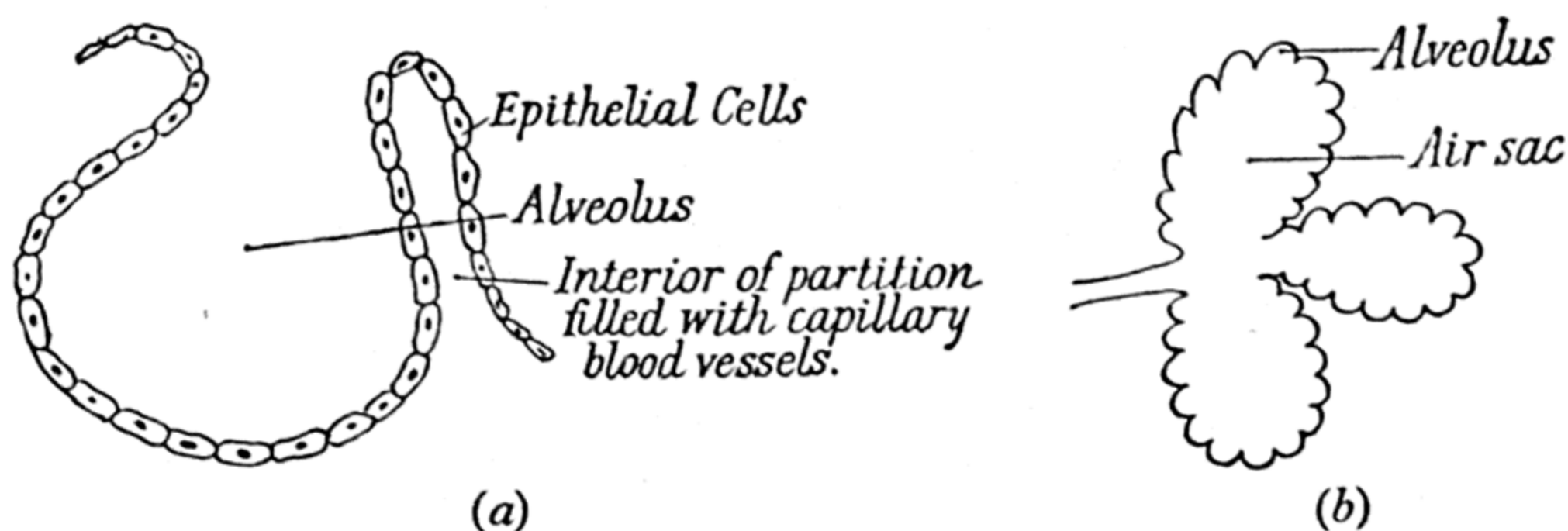


Fig. 171

(a) Alveolus, showing air-space layer of epithelial cells and partition walls containing capillary blood-vessels.

(b) Bronchiolus ending in enlarged air sacs lined with alveoli (about 35 times actual size).

**breast-bone** with them, thus increasing the size of the thorax from front to back. By means of other muscles the diaphragm can be pulled downwards so as to increase the size of the thorax from top to bottom. These two sets of muscles work together, first increasing the volume of the thorax, causing air to enter the lungs, and then decreasing the volume of the thorax, whereupon air is expelled from the lungs.

The normal rate of breathing is about 14 to 18 breaths a minute, and on each occasion about 30 cu. in. of air are inhaled and then exhaled. But the total amount of air in the lungs is much greater than this. By taking a very deep breath, we can breathe in an extra 100 cu. in. of air, and by an extra deep exhalation breathe out an

additional 100 cu. in., so that after taking the deepest possible breath and then making the deepest possible exhalation, we can breathe out a total of  $30 + 100 + 100 = 230$  cu. in. This volume is called the **vital capacity**. Even after the deepest exhalation, the lungs still contain 75 to 100 cu. in. of **residual air** that cannot be expired. In normal breathing the 30 cu. in. taken in mingle with the air already in the lungs, and 30 cu. in. of this mixture is then breathed out.

**EXPERIMENT 86. — To determine one's chest expansion and vital capacity.** Place a tape measure round the chest and measure the greatest girth: (a) after breathing out as much air as possible, (b) after taking as deep a breath as possible. The difference between these two measurements is called the **expansion**.

Take a large bell-jar and, having gummed a strip of paper on the outside, fill the jar with water and invert it in a trough of water in the same way as you would a gas cylinder. Pass the end of a length of rubber tubing under the rim of the bell-jar and then, having taken as deep a breath as possible, close the nostrils with the fingers and breathe out through the rubber tubing, expelling as much air as you can. The air passes into the bell-jar, displacing water. Mark the level of the water inside the jar. By removing the bell-jar from the trough and filling it with water from a measuring cylinder up to the mark on the scale, the volume of air expired (the vital capacity) can be found. Note that 1640 c.c. = 100 cu. in. If the apparatus is to be used a number of times, it will be more convenient to graduate the bell-jar by adding successive known volumes of water and marking these volumes on the gummed strip.

## **Gaseous Exchange in the Blood.**

While in the lungs air parts with some of its oxygen and receives in exchange carbon dioxide and water vapour. This exchange of gases takes place at the surface of the alveoli. Here the capillary blood-vessels are very close to the surface, and the blood contained in them is able to take in oxygen and give out carbon dioxide and water vapour through the very thin walls of the respiratory membrane, which alone separates it

from the air. The very large total area of the alveoli, nearly 100 sq. yd., enables this process to take place at a very rapid rate.

EXPERIMENT 87. — Obtain from a butcher the heart and lungs of a sheep, specifying that the latter must be undamaged. Observe the larynx and epiglottis, and the incomplete rings of cartilage around the trachea which render the latter very difficult to compress. The lungs ("lights") consist of soft spongy pink tissue. Insert a flanged tube of appropriate size into the trachea and tie it tightly so that it cannot slip out. Attach a foot bellows to the tube and by working the bellows cause the lungs to expand. As soon as we stop blowing, the elasticity of the lungs causes them to collapse again. (Why do they not collapse like this when inside the thorax of a living animal?) With a pair of scissors, cut down the windpipe and one of the bronchi, following it into the lung in order to see how it branches.

## Respiration and the Blood.

Blood consists of a fluid called **plasma**, largely water, but containing about 10 per cent of **protein** and mineral salts, and enormous numbers of tiny corpuscles of two kinds. The **white corpuscles** are concerned with the protection of the body against disease. There are about five hundred **red corpuscles** to every white one, and it is the red corpuscles that take oxygen from the lungs to all parts of the body and bring back carbon dioxide in exchange. A red corpuscle is about  $\frac{1}{3000}$  of an inch in diameter, and a drop of blood 1 c. mm. in volume (about the size of a pin's head) contains between 5 and 6 million red corpuscles in the case of a man and between 4 and 5 million in the case of a woman, the total number in the human body being about 25,000,000,000,000, having a total surface area of some 3500 sq. yd. Their red colour is due to the fact that about 90% of their solid matter consists of a red pigment, **hæmoglobin**, a complicated chemical compound which contains a small amount of iron.

This compound combines very readily with oxygen to form a scarlet compound called **oxyhæmoglobin**. This combination takes place in the lungs, and the oxygenated blood is then conveyed to all parts of the body in the manner described below. In the course of its travels, the oxygenated blood gives up its oxygen to convert organic substances in the body into carbon dioxide and water. This process is continually taking place in all parts of the body and is called **tissue respiration**. It is during tissue respiration that the actual oxidation of organic matter occurs and the liberation of its energy takes place. The act of breathing, or **external respiration**, is the outward sign of this inner process. The water formed during tissue respiration renders the blood more dilute, while part of the carbon dioxide enters into a loose chemical combination with the hæmoglobin which has given up its oxygen, and part dissolves in the blood plasma. The blood, now no longer bright scarlet but rather purplish in colour, returns to the lungs, where it exchanges its load of carbon dioxide and its excess water for oxygen. The blood, therefore, acts as a carrier for the oxygen necessary for oxidation, and for the products of the oxidation, which are passed out into the air via the lungs.

### **Circulation of the Blood.**

In order that the blood may act as a carrier for oxygen and for the products of the slow combustion that takes place in the tissues of the body, it is necessary that it should be able to travel from the lungs to all parts of the body, and back again. This is effected by the working of a powerful pump called the heart, and a complicated system of tubes (blood-vessels) of different kinds called **arteries**, **veins**, and **capillaries**.

## The Heart.

The human heart is a great hollow vessel with muscular walls, divided into four compartments, the two upper compartments or **auricles** having thinner muscular walls than the two lower compartments or **ventricles**. The right auricle communicates with the right ventricle, and the left auricle with the left ventricle, by openings that can be closed by valves, arranged in such a manner as to permit of blood passing from auricle to ventricle, but not vice versa. There is no communication between the right and left sides of the heart.

Let us imagine for a moment that the left ventricle is full of bright red oxygenated blood. The ventricle now contracts forcibly. The increased pressure on the blood causes the valves between the left ventricle and left auricle to close, and those between the left ventricle and the **aorta** (fig. 172) to open, and several ounces of blood are forced out into the aorta, the largest artery in the body. This divides into smaller arteries, some conveying blood to the upper part of the body and some to the lower. These in turn divide into smaller and smaller arteries serving the various parts of the body. The walls of the arteries are thick and have elastic muscular walls, which expand when blood is forced into the arteries from the heart. The distended muscular walls of arteries act in much the same way as the compressed air in the air chamber of a force pump (fig. 101, p. 125); in the intervals between successive heart beats, their contraction keeps up the pressure in the arteries and forces the blood onwards. When an artery is cut, as may happen in an accident, the bright red blood spurts out in jerks, each jerk corresponding to a contraction of the ventricle forcing more blood along the artery. The pressure of the blood in a large artery is equal to that of about six feet of water. In the smaller arteries the pressure is less. Where arteries come

near the surface, as, for example, at the wrist, temple, or ankles, the wave of pressure due to each contraction of the ventricle can easily be felt, and is called the **pulse**. The normal rate of the pulse in an adult is about 72 beats a minute.

The arteries finally branch out into a network of innumerable fine tubes called capillaries, a fraction of

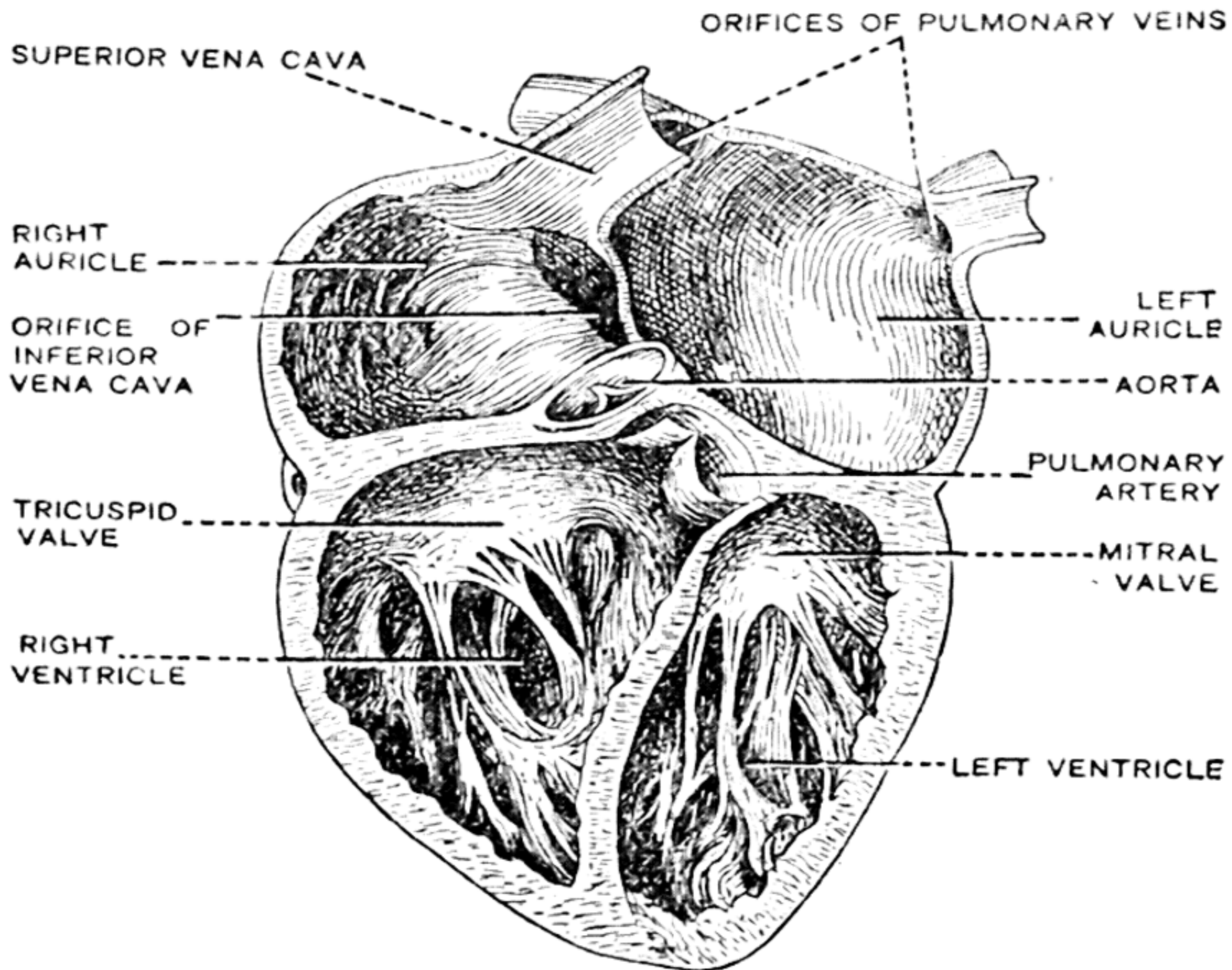


Fig. 172. — Heart opened to show Chambers

an inch in length, and perhaps  $\frac{1}{1800}$  in. in diameter. The capillaries have very thin walls, through which oxygen from the blood can pass to the neighbouring cells, and through which the blood can absorb carbon dioxide and water. The capillaries are so narrow that the blood corpuscles have to pass along them in single file, and most of the pressure of the arterial blood is used up in forcing the blood through this network of fine vessels. The capillaries join together again and allow the blood passing through them to drain into

larger tubes called veins. The blood passes along these veins, which empty into larger and larger veins, and

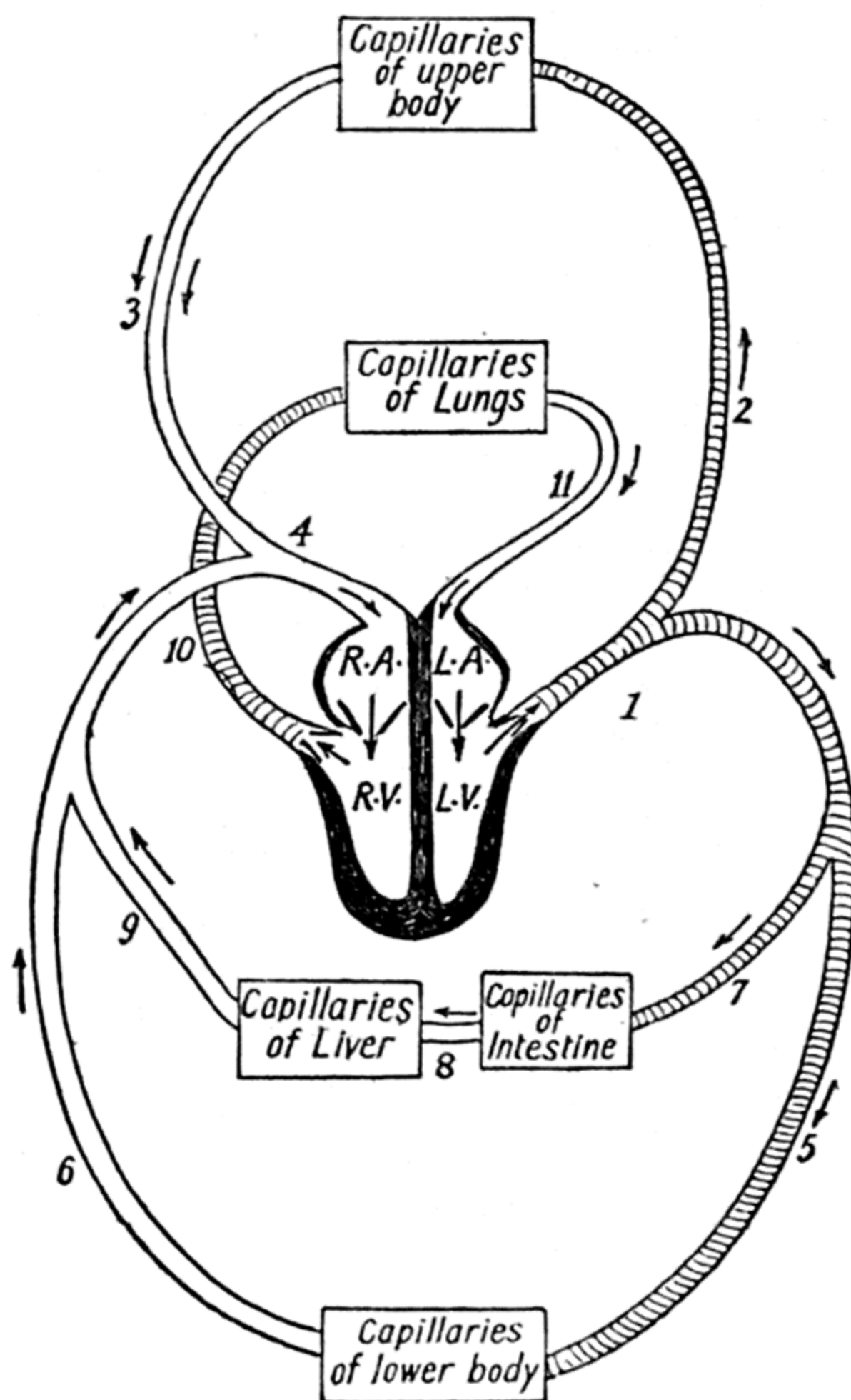


Fig. 173. — Diagram to illustrate the Circulation of the Blood

R.A., right auricle; L.A., left auricle; R.V., right ventricle; L.V., left ventricle; 1, aorta; 2, arteries to upper part of body; 3, veins from upper part of body; 4, great veins (*venæ cavæ*) returning blood to heart; 5, arteries to lower part of body; 6, veins from lower part of body; 7, arteries to intestine; 8, portal vein; 9, vein from liver; 10, pulmonary artery (to lungs); 11, pulmonary vein (from lungs).

finally enters the right auricle of the heart by two great veins called the *venæ cavæ* (sing. *vena cava*). The blood in the veins differs from that in the arteries in

several respects. It is returning to the heart, while that in the arteries is going from the heart; it is at a much lower pressure; and it has given up its load of oxygen and is returning with a load of carbon dioxide and excess water, so that instead of being bright red it is much darker in colour. Veins differ from arteries in having thinner walls, since they have to withstand less pressure, and they contain valves at intervals to keep the flow of blood in the right direction. Valves are unnecessary in the arteries because of the high pressure maintained by the contractions of the ventricle.

It would seem at first sight that the venous blood should return, not to the heart, but to the lungs, where it could obtain a fresh supply of oxygen. Its pressure in the veins, however, is insufficient to force it through the capillaries of the lungs, and so it returns to the central pumping station, where, passing from the right auricle to the right ventricle, it is forced out again at high pressure along the **pulmonary artery** by contractions of the right ventricle. The pulmonary artery differs from all other arteries of the body in that it contains de-oxygenated blood (elsewhere found in veins). The blood passes through the capillaries in the walls of the alveoli of the lungs, where it exchanges its carbon dioxide and excess water for oxygen, and then returns to the left auricle of the heart at low pressure through the **pulmonary vein**, which differs from the other veins of the body in that it contains bright red oxygenated blood (elsewhere found in arteries).

Like all other muscles, the muscles of the heart require a certain amount of rest, and since, unlike all other muscles, the heart muscles have to work when we are asleep as well as when we are awake, they have to get their period of rest in between the beats. During the contraction of the ventricles the base of the heart strikes against the chest wall, causing what is called the **beat** of the heart, which can be both felt and seen.

During sleep the heart beat is as low as 60, but when one is taking violent exercise it may rise as high as 120. Under the latter conditions the ventricles get only about half as much rest while doing nearly twice as much work.

EXPERIMENT 88. — Count your pulse (*a*) while lying down, (*b*) while walking about, (*c*) immediately after running up a flight of stairs.

EXPERIMENT 89. — **To show the structure of a Sheep's Heart, the working of the Valves, and the complete absence of any communication between the right and the left sides of the Heart.** For experimental details for this dissection consult Hill, *Manual of Human Physiology*, 4th edition, pp. 145-52.

EXPERIMENT 90. — **To demonstrate the circulation of Blood in a Tadpole.** Wrap a tadpole round with wet cotton-wool so that its transparent tail is not covered. Place the tadpole on a glass slide and examine the tail through the low power of a microscope. A constant stream of blood corpuscles can be seen passing through the fine capillaries of the tail.

### **The Value of Exercise in Aiding Circulation.**

We have seen that the pressure of the blood in the veins is very low and that the pulse cannot be felt in a vein. If the arm be held downwards motionless for a little while it will begin to swell, for blood accumulates in the veins and has insufficient pressure to drive it back to the heart. On raising the arm above the head, the blood is able to drain downwards. The main cause of venous blood returning readily to the heart is muscular movement, which compresses the veins, and this necessarily drives the blood they contain towards the heart, since the valves in the veins prevent it moving in the opposite direction. In a similar way, the movement of the lungs in breathing also helps the venous circulation. Exercise, by promoting active muscular movement, helps to keep up an active cir-

ulation of the blood, and this plays a large part in keeping the body fit and healthy.

### **To Stop Bleeding from an Artery or Vein.**

Bleeding from a shallow cut soon stops, but, if a wound is deep, a vein or artery may be severed, and in such cases it is necessary to check the flow of blood immediately or the patient may lose a lot of blood or even bleed to death. The bleeding can be stopped by applying pressure to the severed artery or vein on the side *from* which the blood is flowing. If the blood is bright red and escapes in spurts, an artery has been cut, and pressure should be applied on the side of the cut nearer the heart, but if the blood is dark in colour and flows steadily we are dealing with bleeding from a vein, which should be compressed on the side away from the heart. Those who study first-aid learn the courses of the main arteries and veins, and the pressure points at which pressure can best be applied. In most cases, however, it is sufficient to apply pressure immediately over the point where bleeding is occurring. A pad of folded lint, as aseptic as possible, should be placed over the cut, and a fairly tight bandage placed over the lint.

### **How Fishes Breathe: Gills.**

Fishes, living completely immersed in water, do not obtain the oxygen they need for respiration from the atmospheric air, but from air dissolved in water. Although water contains such a large proportion of oxygen, fishes are not able to split water up and utilize the combined oxygen, and for this reason fishes are unable to live in water from which all the dissolved air has been expelled, e.g. by previous boiling. When fishes are kept in a small space such as an aquarium, they will soon use up all the dissolved oxygen, and it is therefore necessary to keep the water aerated by bubbling air

through it, or else to change the water from day to day, unless the aquarium contains a sufficient quantity of green water-plants to oxygenate the water (see p. 286 for the liberation of oxygen by green plants in sunlight).

Watch a goldfish in a bowl of water. It is continually opening and closing its mouth. When it opens its mouth water enters, and when the mouth is closed again this water is forced out by muscular action through a number of **gill slits** on either side of the body behind the mouth. As it passes through these slits, the water is in contact with the **gills**, attached to supports called **gill arches** at the back of the mouth. Certain projections known as **gill teeth** or **gill rakers** strain off solid food particles, which are retained in the mouth. The gills consist of slender branched filaments in which capillary blood-vessels are separated from the water by only a thin **respiratory membrane**. Oxygen dissolved in the water passes through this membrane into the blood, and at the same time the latter parts with its carbon dioxide, which dissolves in the water and is carried away by the current flowing past the gills. In most fishes the gills are protected by a flap called the **gill cover** or **operculum**, which is forced up when water passes through the gills.

EXPERIMENT 91. — Lift the gill cover of a herring and examine the gills. How many gills are there on each side of the head? How do you explain their pink colour? Insert a thin wooden splint into one of the gill slits and push it gently as far as you can. Where does it come out?

## The Respiration of Insects.

All insects breathe by means of a system of **tracheæ**, or air tubes. The openings leading to these are called **spiracles**, of which there may be as many as ten pairs. Air enters these openings, assisted by muscular movements, and passes by means of a branched network of

tubes to all parts of the insect. This method of respiration is very efficient, and enables insects to exhibit great activity. Nevertheless, it would be very unsatisfactory for a larger organism, since the air tubes would have to be longer and the air would not diffuse sufficiently rapidly to deeper parts of the body.

### **Respiration in the Frog.**

A frog has lungs but no diaphragm. In the absence of the latter, air cannot be drawn into the lungs; it has to be forced in by pressure from outside. A frog is able to increase the volume of its mouth cavity by lowering the floor of the mouth. This is done with the mouth closed, and air enters through the nostrils to fill up the increased volume. The nostrils are then closed as well as the mouth, the former by means of thin membranes which act as valves, and on raising the floor of the mouth again by muscular effort the air in the mouth cavity is compressed and some of it is forced out through the glottis into the lungs, which then expand. As soon as the muscles which control the raising of the floor of the mouth relax, the elasticity of the lungs causes the latter to contract and expel air into the mouth and out through the nostrils. A frog, therefore, can breathe only when its mouth is closed.

Frogs are able to absorb oxygen through their skin, although insufficient to supply all their needs. The skin of a frog is thin and always moist, and has a plentiful supply of blood capillaries just beneath it. Oxygen is able to pass in, and carbon dioxide and water vapour out, through this membrane in the same way as through the linings of the lungs. It is because the skin has to be kept moist that frogs are able to live only in damp places.

A frog's heart differs from the human heart in having only one ventricle. Oxygenated blood from the lungs enters the left auricle and de-oxygenated blood from

other parts of the body enters the right auricle. Both the oxygenated and the de-oxygenated blood then pass into a common ventricle. A certain amount of mixing takes place, but the position of the outlets and the system of valves is such that the blood richest in oxygen enters the arteries serving the head, the more mixed blood those serving other parts of the body, and the mainly de-oxygenated blood enters the pulmonary artery and is sent to the lungs, where it is oxygenated.

### QUESTIONS

1. Give a brief account of the lungs and of the air passages leading to them.

2. Describe the part played by the diaphragm and by the ribs in the process of breathing.

3. What are the chief differences between (a) arteries and veins, (b) arterial blood and venous blood?

4. How does the pulmonary artery differ from the other arteries of the body?

5. Explain how blood in the veins is brought back to the heart.

6. Give a brief description of the human heart and explain how it works.

7. What is the difference between *external respiration* and *tissue respiration*? What is the part played by the blood in the process of respiration?

8. Draw a diagram to show the circulation of the blood from the right auricle until it leaves the left ventricle. Describe the changes which occur in the blood during this part of the circulation. L.

9. Explain how (a) fishes, (b) insects, obtain their oxygen for respiration, and how it is conveyed to the various parts of the body.

## CHAPTER XIX

### THE WORK OF THE GREEN PLANT

We have already seen (p. 263) that when starch, sugar, and other organic substances are burned they unite with the oxygen of the air and decompose into two quite simple chemical compounds, i.e. carbon dioxide ( $\text{CO}_2$ ) and water ( $\text{H}_2\text{O}$ ). At the same time a considerable amount of energy, stored up in the original compounds as chemical energy, is liberated as heat and light. Many of these substances which give out much heat when they are burned or oxidized are used by animals as food. A part of the food that an animal eats is converted into actual body tissue, and so brings about growth and increase in weight, but by far the greater part of it is burned up in the body by a process of slow combustion or respiration. The energy so set free supplies the heat necessary in the case of warm-blooded animals if they are to maintain their temperature, and the mechanical energy required for movement and other purposes.

The food that we ourselves eat is derived partly from plants, e.g. vegetables such as the potato, and cereals such as wheat, and partly from animals in the form of meat. The animals we rear for meat all feed on green plants, mainly grass, so that ultimately all our food is derived either directly or indirectly from green plants. In the same way fish feed either on tiny green plants growing in the sea or else on smaller fish that feed on these plants. If for any reason green plants

ceased to grow all over the world, in a very short time all animals would die of starvation.

Plants respire as well as animals, as we have already seen in the case of privet leaves and of germinating seeds (p. 266). Respiration is a process in which complicated compounds such as starch and sugar are broken down to simpler ones with the liberation of energy. If this process is to continue indefinitely it is necessary that there should be some way of forming a fresh supply of the complicated energy-containing compounds.

Green plants are able to build up starch and other energy-containing substances from carbon dioxide, which they obtain from the air, and water, which they get from the soil. Plants, therefore, are able to manufacture their own food. Animals are unable to do this and have to make use of food manufactured by green plants. The growing plant is able to make food more rapidly than is required for its present needs, and the balance is stored up by the plant.

We shall now consider *how* the green plant makes its own food. It will be simplest if we confine ourselves at this stage to the manufacture of **starch**. Plants manufacture other foodstuffs also, such as **vegetable oils**, and very complicated compounds called **proteins**, which contain nitrogen as well as carbon, hydrogen, and oxygen.

**EXPERIMENT 92. — A chemical test for starch.** Take a little soluble starch in a test-tube and shake it up with water. Add a drop of iodine solution. A dark blue colour is formed. Now add a little of the iodine solution to some of the solid starch. The colour is so intense as to be almost black. This simple test will enable us to detect starch in plants.

**EXPERIMENT 93. — To show that leaves which have been exposed to the light contain starch.** Take a leaf of a plant that has been exposed to sunlight for some hours and put it in boiling water for a minute. This will kill the leaf. Have

ready a water bath containing boiling water. Put a beaker of methylated spirits in the bath and immerse the leaf. The hot spirit will dissolve out the green colouring matter from the leaf and leave the latter almost colourless. Remove the leaf from the spirit, wash it with water, place it in a shallow dish and cover it with iodine solution. The leaf soon shows the dark blue coloration due to the action of iodine on starch.

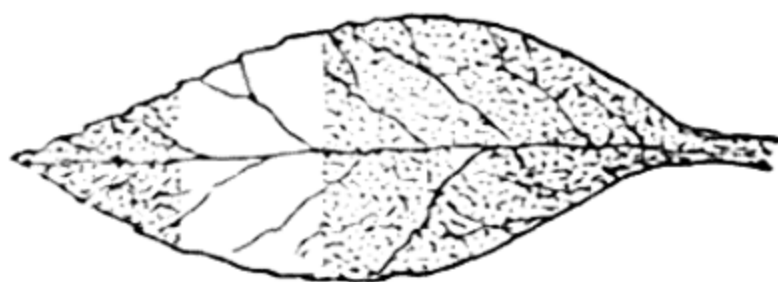
**EXPERIMENT 94. — To show the absence of starch in leaves that have been kept in the dark.** Repeat the preceding experiment with a leaf that has been kept in the dark for some time (two days is usually sufficient). Compare the result with that of the preceding experiment.

**EXPERIMENT 95. — To show that chlorophyll is necessary for the formation of starch in a leaf.** Keep a plant, such as a geranium, which has variegated leaves, in the dark for two days. Expose it to sunlight for several hours and then test a leaf for starch by the method of Experiment 93. Note that no starch has been formed in that part of the leaf from which chlorophyll was absent.

**EXPERIMENT 96. — To show that no starch is formed in the absence of light.** Fix two pieces of cardboard covered with tinfoil across part of a leaf of a plant in such a way that no light can get to the covered part (fig. 174). Leave the plant



Leaf partly covered at A and placed in sunny position.



Same leaf treated with iodine. It shows that the covered part had formed no starch.

Fig. 174.

in the dark for a couple of days so that any starch originally present in the leaf may disappear. Put the plant out of doors on a bright sunny morning, and in the afternoon cut off the leaf and examine it for starch, as in Experiment 93. No starch will have been formed in that part of the leaf which was covered, although the remainder of the leaf will give the starch reaction.

**EXPERIMENT 97. — To show that no starch is formed in the absence of carbon dioxide.** Fit up the apparatus shown

in fig. 175. The bell-jar D stands in a trough containing lime-water and encloses a plant growing in a pot standing on a tripod. Glass tubes connect the bell-jar with the wash-bottle B, containing lime-water, and the wash-bottle A, containing a solution of caustic soda. The tube G is of rubber and can be closed by a clip.

When the clip is open and suction applied to G, either by the mouth or by attaching the apparatus to a filter pump, air is drawn into the bell-jar through the wash-bottles. The caustic soda solution removes any carbon dioxide present in the air, which does not, therefore, turn the lime-water in B

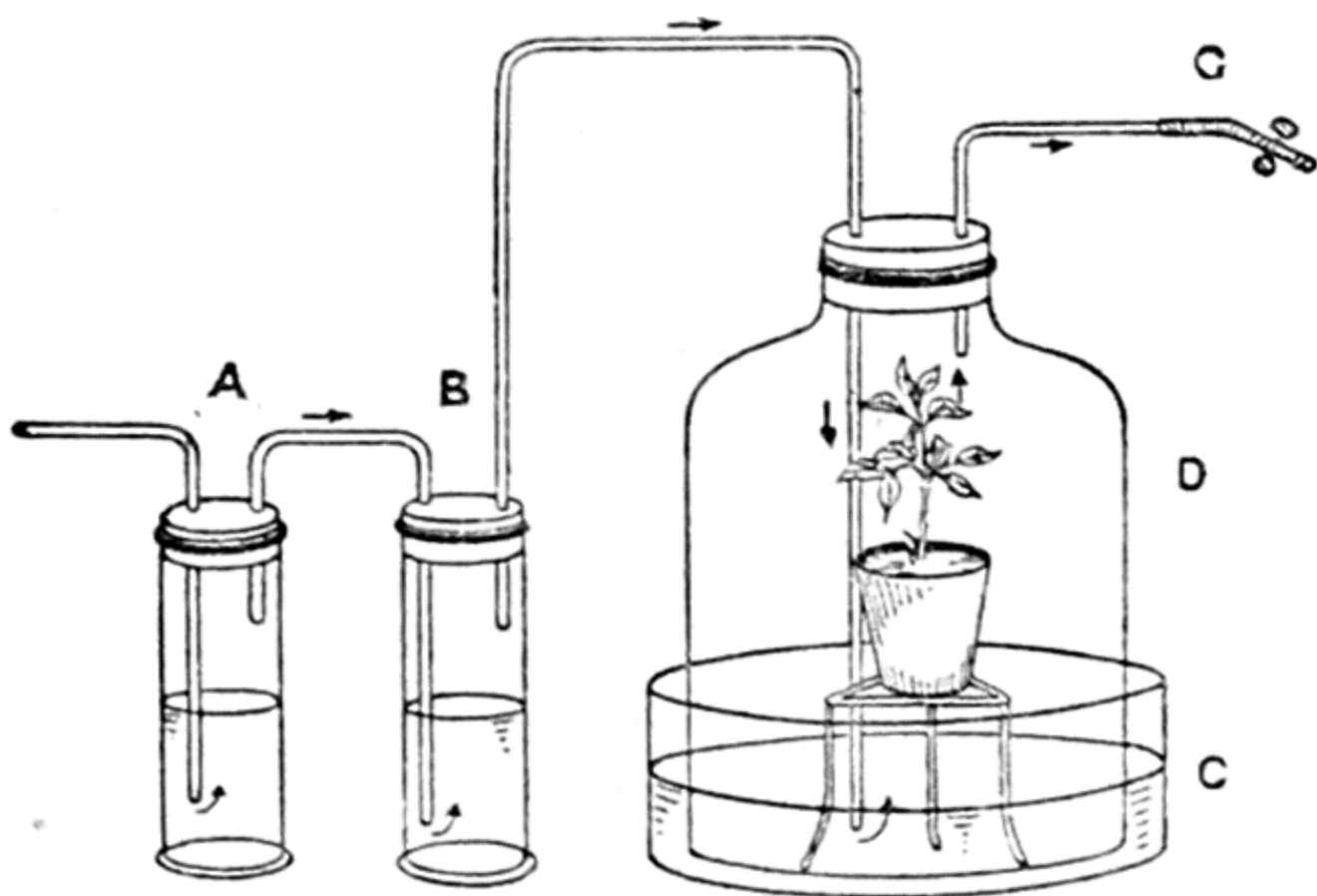


Fig. 175. — Showing how plants use the carbon dioxide in the air

milky. Any carbon dioxide originally present in the bell-jar, or formed by respiration of the plant, is removed by the lime-water in the trough. The apparatus is set up in a sunny place and air is drawn into it once or twice a day. Let the plant grow in this way for some days, and have another growing near it in the open for comparison. After a time the enclosed plant ceases to grow. Remove a leaf in the afternoon, after the plant has been exposed to light, and test it for starch. It will be found that starch is absent.

**EXPERIMENT 98. — To show that a green plant gives off oxygen in sunlight.** Obtain a little waterweed (the Canadian Pondweed, *Elodea canadensis*, or ordinary watercress are suitable) and place it under a glass funnel inverted in a large beaker of water. Fill a test-tube with water and invert it over the spout of the funnel, as shown in fig. 176. Put the beaker

in a dark cupboard. No gas is given off from the plant. In daylight, however, tiny bubbles of gas form on the leaves, and, becoming detached, are collected in the test-tube. The bubbles are given off more rapidly if the plant is exposed to direct sunlight. Leave the apparatus for a few days until the test-tube contains sufficient gas for it to be tested. If the evolution of gas seems rather slow it is advantageous to bubble a little carbon dioxide through the water for a few minutes each day, but in such a way that none of this gas gets into the test-tube. Finally, remove the test-tube from the funnel, placing the thumb over the end, turn the test-tube the right way up, and test the gas with a glowing splint. The splint catches fire, showing that the gas is oxygen. By using somewhat more complicated apparatus it can be shown that the leaves of land plants also give off oxygen in sunlight.

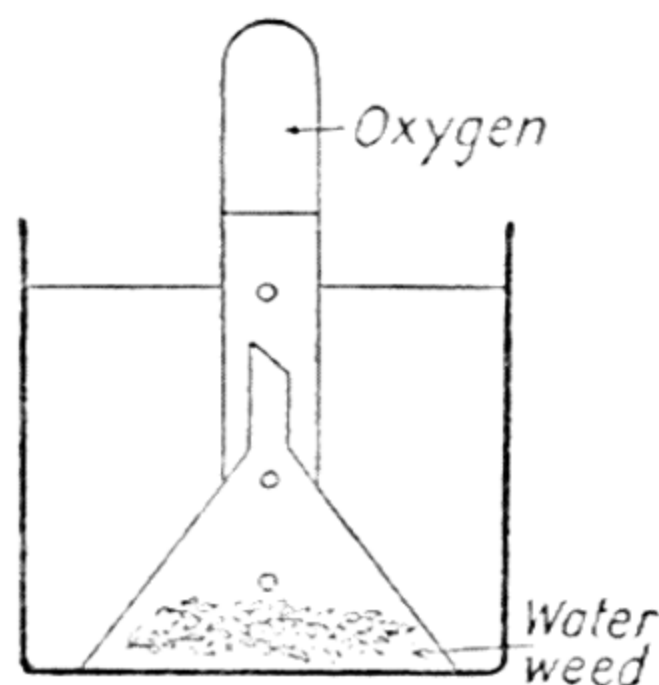


Fig. 176.—Oxygen given off by water weed in sunlight.

### How the Green Plant Manufactures Starch.

The above experiments will have shown us the conditions necessary in order that starch may be formed in the leaves of a plant. These conditions are the presence of (1) chlorophyll, (2) light, (3) carbon dioxide, (4) water. Under these conditions oxygen also is *given off* by the plant.

The exact details of the process are still not known, and it almost certainly takes place in stages. The first stage is the separation of the carbon of the carbon dioxide from its oxygen, which is set free. When carbon combines with oxygen to form carbon dioxide a considerable amount of energy is given out. In order to reverse this process, to get back the carbon and oxygen, we have to return the energy liberated when the carbon dioxide was formed. From where does the green plant get the energy to do this? It gets it from **light**. Light, like heat and electricity, is one of the

forms of energy, and when light falls on chlorophyll a part of the light is absorbed by the chlorophyll. The carbon from the carbon dioxide is then combined with the hydrogen and oxygen from water to form, in the first place, probably sugar, and then starch.

Starch contains a large amount of energy, chemical energy, that is transformed into heat when the starch is burned. All this energy has come from sunlight trapped by chlorophyll. Only plants are able to absorb energy from sunlight and store it up as chemical energy, and that is why only plants are able to manufacture their own food and why, ultimately, all animals depend on plants for their food, their source of energy.

These remarkable chemical reactions take place easily and rapidly in the green plant, and without the aid of heat, because of the part played by the chlorophyll. On a bright summer's day more than two grams of starch may be manufactured per square foot of leaf area. All the carbon present in this starch will have come from that originally present as carbon dioxide in the air, and to obtain it the plant will have had to remove the carbon dioxide normally present in about 100 c. ft. of air.

### **Photo-synthesis and Respiration.**

In the process of respiration, complicated organic substances like starch and sugar are combined with oxygen and broken down into the simpler substances, carbon dioxide and water, and at the same time energy is liberated. The green plant is able to bring about the reverse process as well, the building up of the complicated organic compounds from carbon dioxide and water with the aid of energy obtained from sunlight. This latter process is called **Carbon Assimilation** or **Photo-synthesis**. Photo-synthesis takes place only in sunlight and only in those parts of a plant that contain chlorophyll and are therefore green in colour.

Respiration occurs in all parts of a plant, whether they contain chlorophyll or not, and at all times of the day and night, irrespective of the presence or absence of light. A large plant contains more carbon and more energy stored in it than a small one, so that growth would be impossible unless more carbon dioxide was taken in during photo-synthesis than was given out in respiration. The rate at which carbon assimilation occurs is quite independent of that at which respiration occurs, and in sunlight photo-synthesis is very rapid indeed, so much more rapid than respiration that more starch is manufactured in the hours of daylight than is used up in respiration day and night together. The balance is stored for future need. During light, therefore, plants produce more oxygen than they require for respiration and so, on the whole, oxygen is given off. At night, on the other hand, photo-synthesis ceases, and, since respiration still continues, carbon dioxide is given off.

It was at one time usual to remove flowers from an invalid's room at night, because during the dark they give out carbon dioxide in respiration. This is quite unnecessary, however, as the amount of gas given off by an average pot plant is very much less than that from, for example, a lighted candle.

### **The Circulation of Air in a Plant.**

Air is able to circulate throughout the tissues of a plant, for the cells are always so arranged that there is space around them in which the air can move. The cells are by no means all spherical, or even nearly so, but we can get some idea of the arrangement if we think of a number of round balls or oranges packed in a box. Each is in contact with all the adjacent ones, yet there is plenty of air space around them.

On the top and bottom surfaces of leaves and other

plant organs, there is a layer of cells that fit closely together, and that have thick outer walls through which water and air cannot penetrate. This layer is called the **epidermis** (fig. 177). But the epidermis

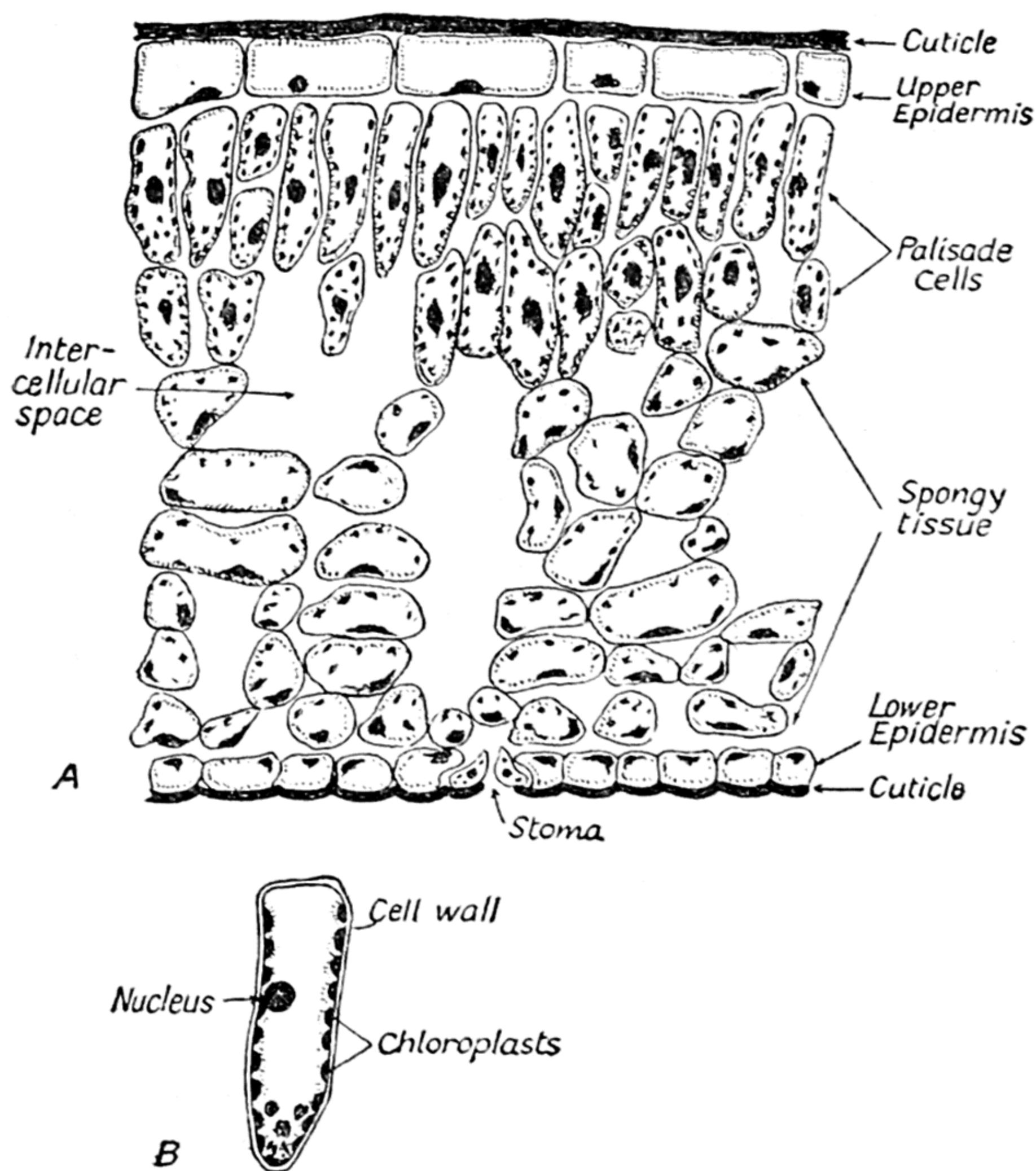


Fig. 177. — Transverse Section of part of a leaf

contains very many tiny pores or openings called **stomata** (sing. **stoma**). In some plants stomata are found on stems and even on flowers, as well as on both sides of the leaves, but in most plants they are much more numerous on the leaves. They are usually more numerous on the lower side of the leaf than on the

upper, from which side they are entirely absent in many woody plants and trees. Stomata are usually very small, and there may be as many as 200 or 300 for every square millimetre of surface. It has been found that air passes even more easily in and out of the leaf through these tiny stomata than if there were no impermeable epidermis at all, and it could enter all over the surface of the leaf.

At the entrance to each stoma are two cells called **guard cells**, which, although in the same layer as the epidermis, are quite different from epidermal cells in shape. These also contain chlorophyll, which epidermal cells do not. The guard cells have thin walls, and by absorbing water from neighbouring cells they are able to swell out and so close the opening of the stoma, thus restricting the flow of air through the leaves. We shall see later why this is sometimes desirable.

Immediately behind each stoma there is usually quite a large air space which communicates with the smaller air spaces between the other cells of the leaf. Immediately under the upper epidermis are found one or two layers of rather elongated and brick-shaped cells arranged with their long axis vertical, i.e. in the direction in which light normally falls on the leaf. These cells are called **palisade tissue** and contain many chlorophyll granules. They receive the light falling on the leaf before the cells below them, which contain less chlorophyll, and it is in the palisade tissue that the bulk of the photo-synthesis of the leaf takes place. Although the cells look tightly packed together, air can circulate between them, for they are in contact over only a part of their surface.

The walls of the cells (except the outer walls of the epidermis) are composed of **cellulose**, which is permeable to water, and, since the cell sap inside the cell consists mainly of water, the outsides of the cell walls are always moist. When air containing carbon dioxide

comes in contact with these walls, the carbon dioxide dissolves readily in the film of moisture on the outside of the wall and passes through the cell wall in solution by diffusion. Inside the cell the water containing carbon dioxide comes in contact with the chlorophyll granules, and now, when light is falling on the leaf, the chemical reactions take place by which sugar and starch are formed. The oxygen liberated passes out by diffusion through the cell wall and mixes with the air in the intercellular spaces, thereby rendering it richer in oxygen. In the same way the oxygen required for respiration diffuses in through the permeable cellulose walls of the cells, and the carbon dioxide formed diffuses out. The cell walls of plant cells, therefore, constitute the plant's **respiratory membrane** (see p. 280).

However dry the air may be that enters a leaf, it is always damp when it finds its way out again, because moisture from the outside of the cell walls has been evaporating into it. Consequently, plants lose large quantities of water in this way, especially in hot weather, when evaporation is most rapid. On a hot summer's day a large forest tree may lose as much as a ton of water. All this has to be absorbed by the roots, and consequently it is to the benefit of the plant that there should be as little water wasted as possible. The loss of water could be stopped almost entirely by closing all the stomata, but if this happened photo-synthesis would stop also, since no carbon dioxide would enter. What actually happens is that the stomata open in the light, when photo-synthesis is possible, and close in the dark, when it is not. The guard cells are sensitive to light and open when stimulated by it, closing when the stimulus is withdrawn.

EXPERIMENT 98. — **To show that a plant loses water through its leaves.** Place a freshly-cut stem with a few leaves attached in a wide-mouthed flask, so that the end of the stem is beneath the surface of water in a beaker (fig. 178).

Plug the mouth of the flask with cotton-wool, or pass the stem through a small hole in a cork, thus preventing water vapour from the beaker entering the flask. After a little while the air inside the flask becomes saturated with water vapour, and the walls become misty as tiny drops of liquid condense on them. That this liquid is water can be shown by adding a little anhydrous copper sulphate, which turns blue.

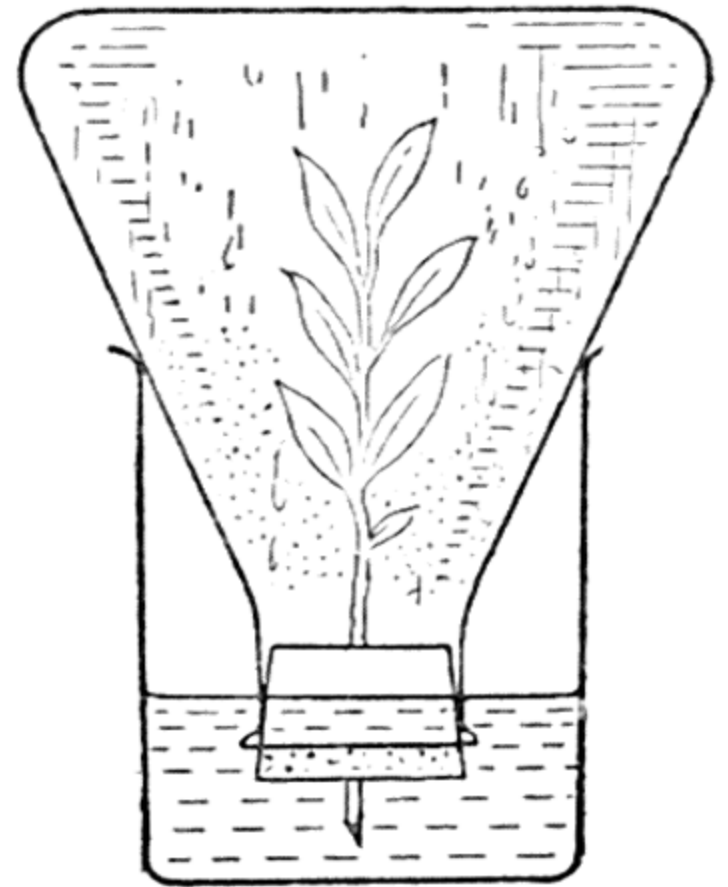


Fig. 178.—A plant loses water through its leaves

EXPERIMENT 99. — To show that carbon dioxide enters a leaf through the stomata. Take a plant that has been kept in the dark for two days. Smear one leaf with vaseline all over the upper surface, a second one all over the lower surface, and a third over both surfaces. Expose the plant to strong light for some hours, and then test for starch all three leaves and also an untreated leaf as control. The vaseline blocks the stomata so that no gases can pass through. It will be found that the leaf smeared on both surfaces has formed no starch, and that the leaf smeared on the upper surface has formed more than that smeared on the lower surface.

## QUESTIONS

1. What conditions are necessary before a plant can manufacture food?
2. What are *stomata*? Why do they close at night? Is this advantageous to the plant?
3. Explain why a sufficient supply of green water plants growing in an aquarium may make it unnecessary to aerate the water.
4. What is a *respiratory membrane*? Illustrate your answer by reference to (a) a plant, (b) an animal.
5. "Animals expend energy, but plants are storers of energy." What do you understand by this statement?

# INDEX

---

- Aberration, spherical, 89.
- Acetylene, 232.
- Acids, 226.
- Air and burning, 220-6.
  - composition of, 229-30.
  - liquefaction of, 231.
  - residual, 271.
  - respired, 264.
- Alcohol, 156, 157, 173, 174, 262-3, 266.
- Altimeter, 120.
- Alveoli, 268-72.
- Amœba, 164-7, 168, 169.
- Amphibia, 146.
- Annuals, 15.
- Anode, 242.
- Anther, 3, 6.
- Antirrhinum, 4, 11, 15, 160.
- Anus, 21.
- Aorta, 274.
- Aperture, 89.
- Apple, 10.
- Archimedes' Principle, 32, 96-7, 103.
- Argon, 229, 230.
- Artery, 217, 273, 274, 275, 277, 279.
- Ash, 11.
- Atom, 252.
- Atomic theory, 252-9.
  - weights, 255-6.
- Auricles, 274.
- Axil, 4.
- Axis, principal, 80.
  
- Balance, chemical, 33, 36.
  - spring, 33, 183.
  - wheel, 47.
- Ball bearings, 201.
- Balloon, lifting power of, 104-5.
- Barograph, 119.
- Barometer, 114-20.
  - aneroid, 118, 119.
  - fortin, 117.
  - mercury, 114, 118.
- Bases, 226.
- Beech, 9.
- Beer, 174.
- Benzene, 152.
- Biceps, 193.
- Biennial, 15.
- Bleaching powder, 228.
- Blood, 271-9.
  - circulation of, 273-9.
- Blowpipe, oxy-hydrogen, 232.
- Bones, 208-18.
- Boyle's law, 121-3.
- Brain, 210.
- Brain-box, 209.
- Bread-making, 174.
- Breast-bone, 270.
- Breathing, *see* Respiration.
- Brewing, 174.
- Broncheoli, 268.
- Bronchi, 268.
- Budding, 172.
- Bulb, 18-9.
- Bunsen burner, 233-5.
- Burning, *see* Combustion.
  
- Calipers, 29.
- Calx, 220.
- Calyx, 3, 7.
- Campanula, 11.
- Campion, 11.
- Capillaries, 217, 273, 275.
- Capsule, 3.
- Carbon assimilation, 284-93.
- Carbon dioxide, 173, 221, 229, 230, 260-2, 285, 286.
- Carnation, 17.
- Carpels, 3.
- Carrot, 15.
- Cartilage, 211, 216.
- Catalysis, 227-8.
- Cathode, 242.
- Caustic, by reflection, 90.
- Celery, 138.
- Cell, 168-9, 171.

- Cellulose, 168, 174, 291.  
 Chlorophyll, 137, 173, 174, 177, 178, 285, 287, 288.  
 Chloroplast, 171.  
 Cilia, 269.  
 Clavicle, 213.  
 Cleavage, 158.  
 Clitellum, 22.  
 Cloaca, 140.  
 Clover, red, 7.  
 Combustion, 220-6, 230.  
   — air necessary for, 230-1, 233.  
   — air in coal gas, 234-5.  
   — alcohol, 262-3.  
   — candle, 220, 224.  
   — carbon, 226, 260.  
   — coal, 232.  
   — hydrogen, 239-40.  
   — metals, 220, 233.  
   — methylated spirits, 220, 221, 232.  
   — organic matter, 262-3.  
   — petrol, 222, 232.  
   — phosphorus, 222, 228.  
   — slow, 228, 265.  
   — starch, 262-3.  
   — sulphur, 226.  
 Components of a force, 185.  
 Compounds and mixtures, 251, 248-9.  
 Concrete, reinforced, 48.  
 Conduction of heat, 58-61.  
 Conjugation, 23, 171, 177.  
 Convection in liquids, 61-3.  
   — in gases, 64-5, 221.  
 Copper oxide, 243-4.  
 Copper sulphate, 137, 157, 160, 161, 162, 263.  
 Corm, 18-19.  
 Corolla, 3, 7.  
 Cotton, 12.  
 Cotyledons, 15, 129-32, 133.  
 Couch-grass, 18.  
 Cranium, 210.  
 Crocus, 19.  
 Crystallization, 158-62.  
   — water of, 161.  
 Current, thermo-electric, 57.  
 Curvature, centre of, 80.  
 Cylinder, measuring, 30.  
 Cyst, 167.  
  
 Daisy, 17.  
 Dandelion, 12.  
 Deliquescence, 162.  
 Delphinium, 11.  
 Density, 92-105.  
   — of gases, 103-5.  
   — of liquids, 94-5, 98-100.  
  
 Density of solids, 92-8.  
 Density-bottle, 94.  
 Devitrification, 159.  
 Diaphragm, 269-70.  
 Diatoms, 165.  
 Digestion, 166, 168.  
 Dimorphous, 160.  
 Distillation, 149-50, 174.  
   " Dry ice ", 45.  
  
 Earthworm, 21.  
 Eclipses, 72, 73.  
 Ectoplasm, 163.  
 Efficiency, 199-200.  
 Efflorescence, 162.  
 Effort, 190.  
 Egg, 23, 141-2, 146.  
 Elastic limit, 183.  
 Elbow, 194, 215.  
 Element, chemical, 247, 256.  
 Embryo, 129, 175.  
 Endoplasm, 163.  
 Energy, 203-6.  
   — chemical, 249-50.  
   — food a source of, 283.  
   — heat a form of, 205, 249.  
   — kinetic, 204-5.  
   — potential, 204-5.  
 Ephemeral, 15.  
 Epidermis, of leaves, 289-91.  
 Epiglottis, 268.  
 Epsom salts, 153.  
 Equations, chemical, 257-8.  
 Ether, 156.  
 Etiolation, 137-8.  
 Eureka can, 32.  
 Excretion, 166.  
 Expansion, apparent, 42.  
   — applications of, 46-8.  
   — of gases, 43-4.  
   — of liquids, 42-3.  
   — of solids, 40-41.  
  
 Fahrenheit, 52.  
 Femur, 213.  
 Fermentation, 173-4.  
 Ferrous sulphide, 249.  
 Fibula, 214.  
 Filtration, 151, 250.  
 Fire extinguisher, 221.  
 Fission, 166.  
 Fixed points, 50.  
 Flame, 232-3.  
 Flotation, 72.  
 Flower, 3.  
 Flowering plants, 1.  
 Focal length, 81, 86-7.  
 Focus, principal, 81.

- Food and energy, 283.  
 Force, 180-1.  
 Forces, moment of, 187-94.  
   — parallel, 185.  
 Friction, 180, 181, 182, 197.  
   — liquid, 202.  
   — uses of, 200-1.  
 Frog, 140-6.  
 Fructification, 177.  
 Fruits, 8.  
 Fulcrum, 190.  
 Fungi, 177.
- Galileo, 124.  
 Gases, 44.  
 Gauges, 28, 29.  
   — water, 111.  
 Gelatin, 215.  
 Geotropism, 134-7.  
 Germination, 128-33, 266.  
 Gills, 142.  
 Glauber's salt, 153.  
 Glottis, 268.  
 Goose-grass, 13.  
 Gravity, force of, 180, 182, 197.  
   — specific, 92-105.  
 Gristle, 211.  
 Ground Ivy, 17.  
 Groundsel, 13.  
 Growth of seedlings, 133.  
 Guard cells, 291.  
 Gullet, 268.
- Hæmoglobin, 272.  
 Hazel, 7, 9.  
 Heart, human, 274-8.  
   — of frog, 281-2.  
   — of sheep, 282.  
 Heat, 38-68.  
   — a form of energy, 205.  
 Heliotropism, 133-4, 136, 137.  
 Helium, 105, 229, 230.  
 Hibernation, 22, 143.  
 Hilum, 129.  
 Hip bones, 212-3.  
 Hooke, 183.  
 Hop, 7.  
 Horse-chestnut, 7.  
 Humerus, 193, 213.  
 Humus, 23.  
 Hydrocarbon, 233-4.  
 Hydrogen, 104-5, 237-40.  
 Hydrometer, 99-100.  
 Hydroplane, 102.  
 Hydrotropism, 136.  
 Hyphæ, 175.  
 Hypsometer, 50.
- Iceland spar, 158, 160.  
 Ignition point, 221.  
 Image in plane mirror, 76-9.  
   — real, 83.  
   — virtual, 77.  
 Incandescence, 44.  
 Inflorescence, 4.  
 Invar, 47.  
 Inversion, lateral, 79.  
 Invertebrates, 217.  
 Iodine, solubility of, 157.  
 Irritability, 133-9.  
 Isomorphism, 159.
- Joints, 215-6.
- Klinostat, 136.  
 Knee, 215.
- Lactometer, 101.  
 Lamina, 3.  
 Larva, 144.  
 Larynx, 268.  
 Law, Boyle's, 121-2.  
   — Hooke's, 183.  
   — of constant proportions, 248, 259.  
 Leaves, 2.  
 Lever, 190-3.  
 Ligaments, 193, 211.  
 Light, diffused, 76.  
   — energy of, 287-8.  
   — nature of, 69.  
 Lime, 11.  
 Lime-water, 262, 263.  
 Liquids, 44.  
 Load, 190.  
 Lubrication, 201.  
 Lungs, 143-4.
- Magnesium, burns in air, 233.  
   — burns in carbon dioxide, 260.  
   — decomposition of steam by, 241.  
 Magnesium oxide, 241, 260.  
   — sulphate, 153.  
 Magnification, 86-88.  
 Manganese dioxide, 225, 227, 228.  
 Manometer, 109.  
 Mating, of frogs, 140, 144.  
 Matter, conservation of, 246, 253.  
 Mechanical advantage, 191, 194-5, 200.  
 Metamorphosis, 193-4.  
 Metric system, 27.  
 Micropyle, 5, 129.  
 Mirrors, 75, 80-90.  
   — concave, 80.  
   — convex, 80, 87-9.  
   — cylindrical, 89.

- Mirrors, paraboloidal, 90.  
 Molecule, 254.  
 Molecular weight, 255.  
 Moment, of a force, 189.  
 Moments, principle of, 190.  
 Motion, perpetual, 198-9.  
 Moulds, 175-8.  
 Mucor, 175-7.  
 Mucus, 268.  
 Muscle, 193, 216-7, 270.  
 Mushrooms, 177.  
  
 Nectary, 5.  
 Neon, 229, 230.  
 Nitre, 154, 159.  
 Nitrogen, 224.  
 Nucleus, 163, 168.  
  
 Oak, 7, 9.  
 Offsets, 17.  
 Operculum, 280.  
 Ovary, 3, 8, 24.  
 Ovules, 3.  
 Oxidation, 245.  
 Oxides, 230.  
 Oxygen, 224, 225-32, 285-6.  
   — liquid, 231-2.  
   — percentage in air, 222, 228.  
 Oxyhæmoglobin, 273.  
  
 Palisade tissue, 291.  
 Parallax, 30, 78.  
 Pascal, 109, 116.  
 Patella, 214.  
 Pea, 11, 15.  
 Pedicel, 3.  
 Pendulum, 47.  
 Penicillium, 178.  
 Penumbra, 71.  
 Perennial, 15.  
 Pericarp, 8, 9.  
 Periscope, 80.  
 Petals, 3.  
 Petiole, 3.  
 Petrol, 156.  
 Phalanges, 214.  
 Phosphorus, 222, 228.  
 Photo-synthesis, 284-93.  
 Pipette, 31.  
 Pistil, 3, 6.  
 Plasma, 272.  
 Platinite, 48.  
 Platinum, 48.  
 Plimsol line, 102.  
 Plum, 9.  
 Plumule, 129-30, 131.  
 Pole, of mirror, 80.  
 Pollen, 3.  
 Pollination, 5-7.  
 Poplar, 7, 12.  
 Poppy, 11.  
 Potassium bichromate, 159, 228.  
   — chlorate, 154, 225, 227.  
 Potato, 15, 16.  
 Pressure, 107.  
   — atmospheric, 114-16.  
 Process, bony, 211.  
 Protective coloration, 146.  
 Protein, 272, 284.  
 Protoplasm, 164, 166-8.  
 Pseudopodia, 163.  
 Pulley, 184, 194-6.  
 Pulse, 275.  
 Pumps, 123-6.  
 Pyrometer, 57.  
  
 Radicle, 129-33.  
 Radius, 193, 212.  
 Receptacle, 10.  
 Reduction, 245.  
   — of copper oxide, 243-4, 245.  
 Reflection of light, 74-90.  
   — laws of, 74-5.  
 Reproduction, 168.  
   — amœba, 166.  
   — earthworm, 23-4.  
   — fission, 166.  
   — flowering plant, 4-8, 15-19.  
   — frog, 140-2.  
   — mucor, 175.  
   — sexual, 171.  
   — spirogyra, 171.  
   — vegetative, 15, 171-2.  
   — yeast, 172.  
 Resistance (force), 190.  
 Respiration, 144, 288, 289.  
   — human, 264-5.  
   — of fishes, 279.  
   — of frog, 281.  
   — of insects, 281.  
   — of plants, 266.  
   — tissue, 273.  
   — external, 273.  
   — liberates energy, 265, 283-4.  
 Respiratory membrane, 271, 280, 292.  
 Resting period, 128.  
 Resultant, 185.  
 Rhizome, 18.  
 Ribs, 213, 270.  
 Root hairs, 1.  
  
 Sacrum, 212.  
 Salamander, 146.  
 Seed dispersal, 10, 11-14.  
 Seeds, 10, 128, 175.

- Segmentation of egg, 141-2.  
 Shadows, 70-3.  
 Shepherd's Purse, 1, 10, 15.  
 Skeleton, human, 208-18.  
 — of frog, 218.  
 Skull, 209-10.  
 Snapdragon, 4, 11, 15, 169.  
 Sodium, 240.  
 Sodium bicarbonate, 153.  
 Sodium nitrate, 159, 160.  
 Sodium sulphate, 153, 160.  
 Solids, 44.  
 Solubility, 153-6.  
 Solution, 148-57.  
 — chemical, 238-9, 246.  
 — saturated, 154.  
 — super-saturated, 160.  
 Solvent, 148, 156.  
 Spawn, frog, 140.  
 Sperm, 23.  
 Spermathecæ, 24.  
 Spinal cord, 210-12.  
 Spirogyra, 170-1.  
 Spore, 173, 175.  
 Spring, helical, 182.  
 Springs, of water, 112.  
 Stamens, 3.  
 Starch, 174, 262-3, 284.  
 Steam, decomposition of, 241, 242.  
 Stem, 2.  
 — underground, 16.  
 Sternum, 213.  
 Stigma, 3, 6.  
 Stimulus, 133-9.  
 Stolon, 17.  
 Strata, 112.  
 Strawberry, 16.  
 Sublimation, crystallization by, 158.  
 Submarine, 102.  
 Sugar, 157, 172, 173, 174, 265, 266.  
 Sulphur, 160, 174, 262-3.  
 Sycamore, 7, 9, 11.  
 Symbols, chemical, 256-8.  
  
 Tadpole, 142-4.  
 Tap-root, 1.  
 Teeth, of frog, 145.  
 Temperature, 39.  
 — of human body, 55.  
 Tendons, 193.  
 Testa, 129.  
 Thermometer, 39, 49-57.  
 — alcohol, 54, 56.  
 — clinical, 55.  
 — mercury, 49.  
  
 Thermometer, Six's maximum and minimum, 56.  
 Thistle, 13.  
 Thorax, 43, 269.  
 Tibia, 214.  
 Tissue, 169.  
 Toad, 146.  
 Toadstools, 177.  
 Thrust, 107, 194.  
 Trachea, 268.  
 Triceps, 193.  
 Tropisms, 133-7.  
 Tuber, 16.  
 Turnip, 15.  
  
 Ulna, 193, 200, 213.  
 Umbra, 71.  
 Unit, 26.  
 Urostyle, 218.  
  
 Vacuole, 166, 171.  
 Vital capacity, 271.  
 Vein 217, 273, 276, 277, 278, 279.  
 Velocity ratio, 192, 195, 200.  
 Vena cava, 276.  
 Ventilation, 65.  
 Ventricles, 274.  
 Vernier, 27.  
 Vertebrae, 210-12.  
 Vertebrates, 217.  
 Viscosity, 202-3, 45.  
 Vocal cords, 268.  
  
 Washing soda, 162.  
 Water, composition of, 239-44.  
 — distilled, 149.  
 — electrolysis of, 242-3.  
 — mineral, 153.  
 — natural, 148, 150, 152.  
 — sea, 101, 152.  
 Water vapour, 162, 229.  
 Weight, 180, 184.  
 Well, artesian, 112.  
 Wheel, 181.  
 Willow, 7.  
 Willow-herb, 12.  
 Winter, 14.  
 Work, principle of, 196-8.  
  
 Yeast, 172-4, 266.  
 Yield point, 183.  
 Yolk, 142.  
  
 Zinc sulphate, preparation of, 238-9.  
 Zygote, 171, 177.



